Large-scale automatic generation of hydrological input from resistivities and boreholes

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Large-scale automatic generation of hydrological input from resistivities and boreholes

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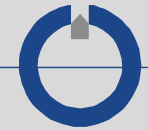
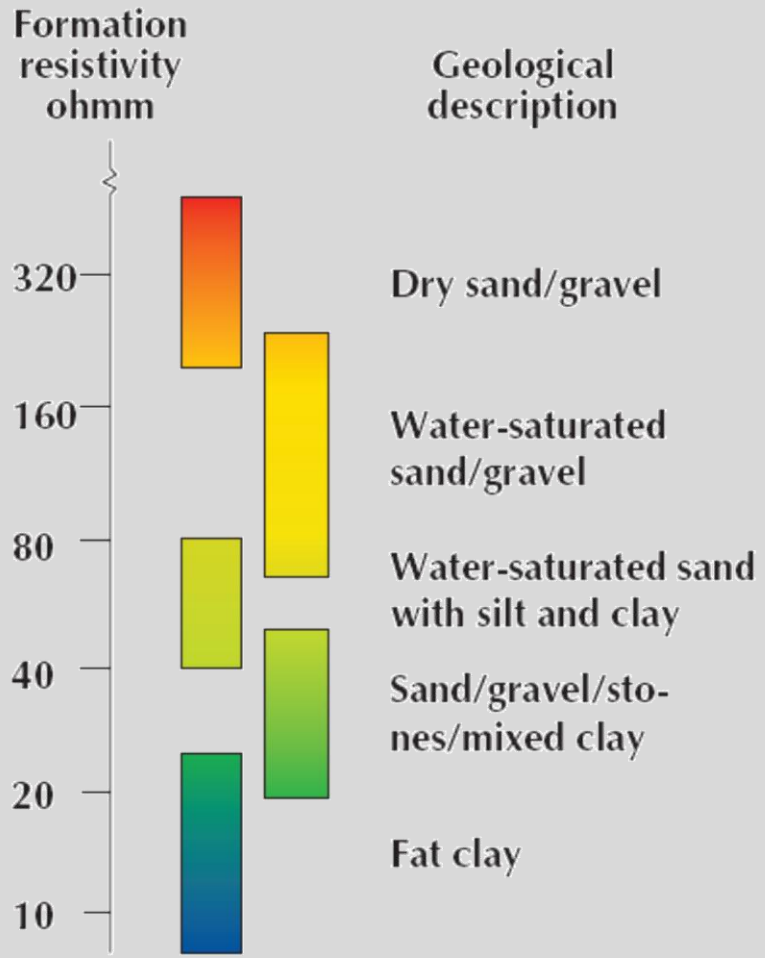
Motivation

- **No one really cares about resistivity or conductivity !**
- **The end-user cares about**
  - Lithology
  - Hydrological parameters
  - Pollution
  - Salt load
  - Geotechnical



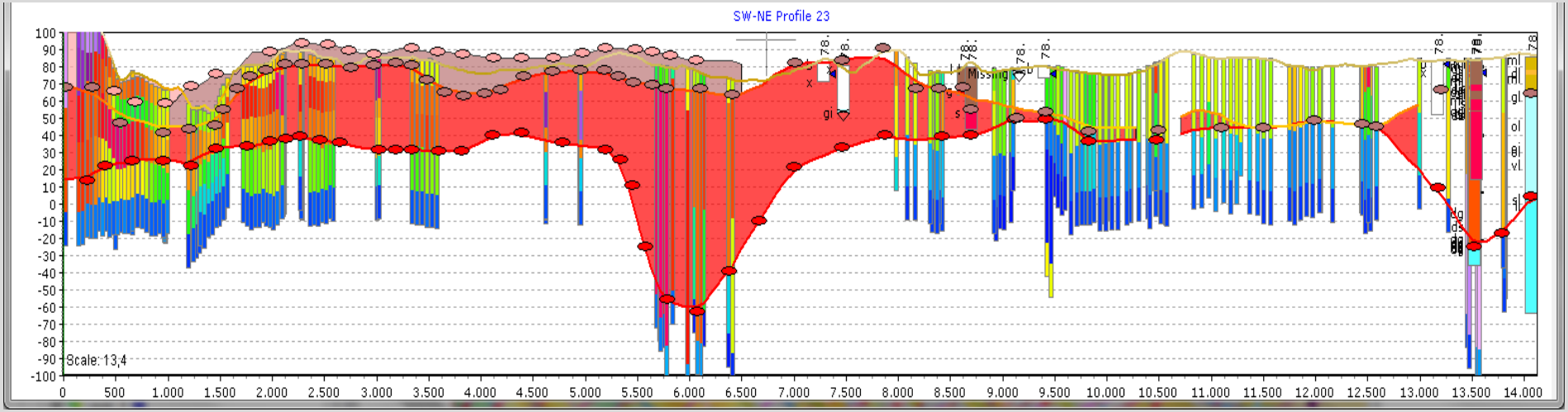
Motivation

- **Low resistivity**
  - clay dominated sediments
  - impermeable
- **High resistivity**
  - sandy sediments
  - permeable



Motivation

- **Boreholes → Direct information**
  - Typically lithology
- **Large scale geophysical surveys → Resistivity information**
- **Derived products**
  - Resistivity → Lithology → Hydrology

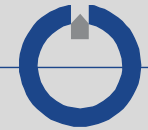


Motivation

- **Boreholes → Direct information**
  - Typically lithology
- **Large scale geophysical surveys → Resistivity information**
- **Derived products**
  - Resistivity → Lithology → Hydrology
- **We present an inversion concept that:**
  - integrate geophysical and borehole information to create 3D clay/sand distributions
  - use the clay/sand distribution to build hydrological classes for objective input to groundwater models

Outline

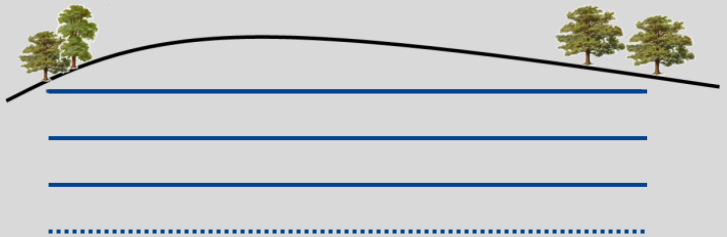
- Motivation
- **Part 1**
  - Methodology : Clay-fraction using boreholes, geophysics and inversion
  - Field example
- **Part 2**
  - Methodology : Classification for groundwater models
  - Field example continued
- **Summary and Discussion**



Methodology – part 1

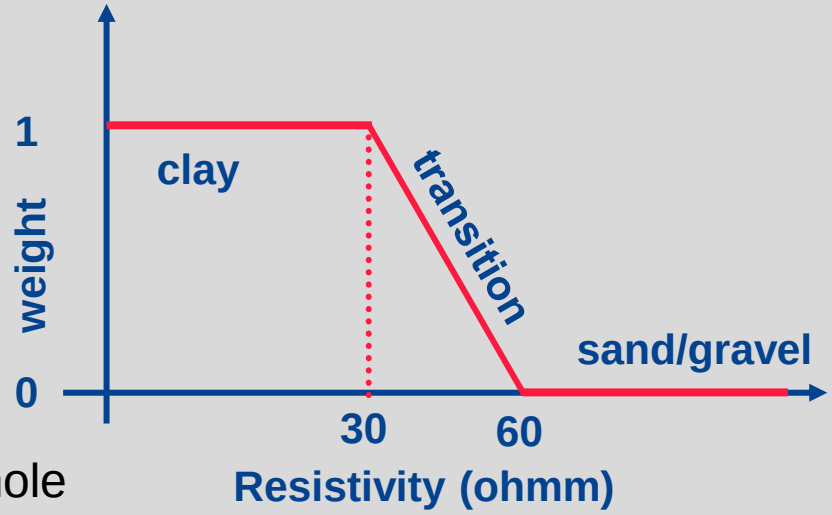
Derived parameter from resistivity models

- Cumulated meters of clay in elevation intervals→ clay fraction



Translator model

- Translate resistivity to a clay fraction in 3D

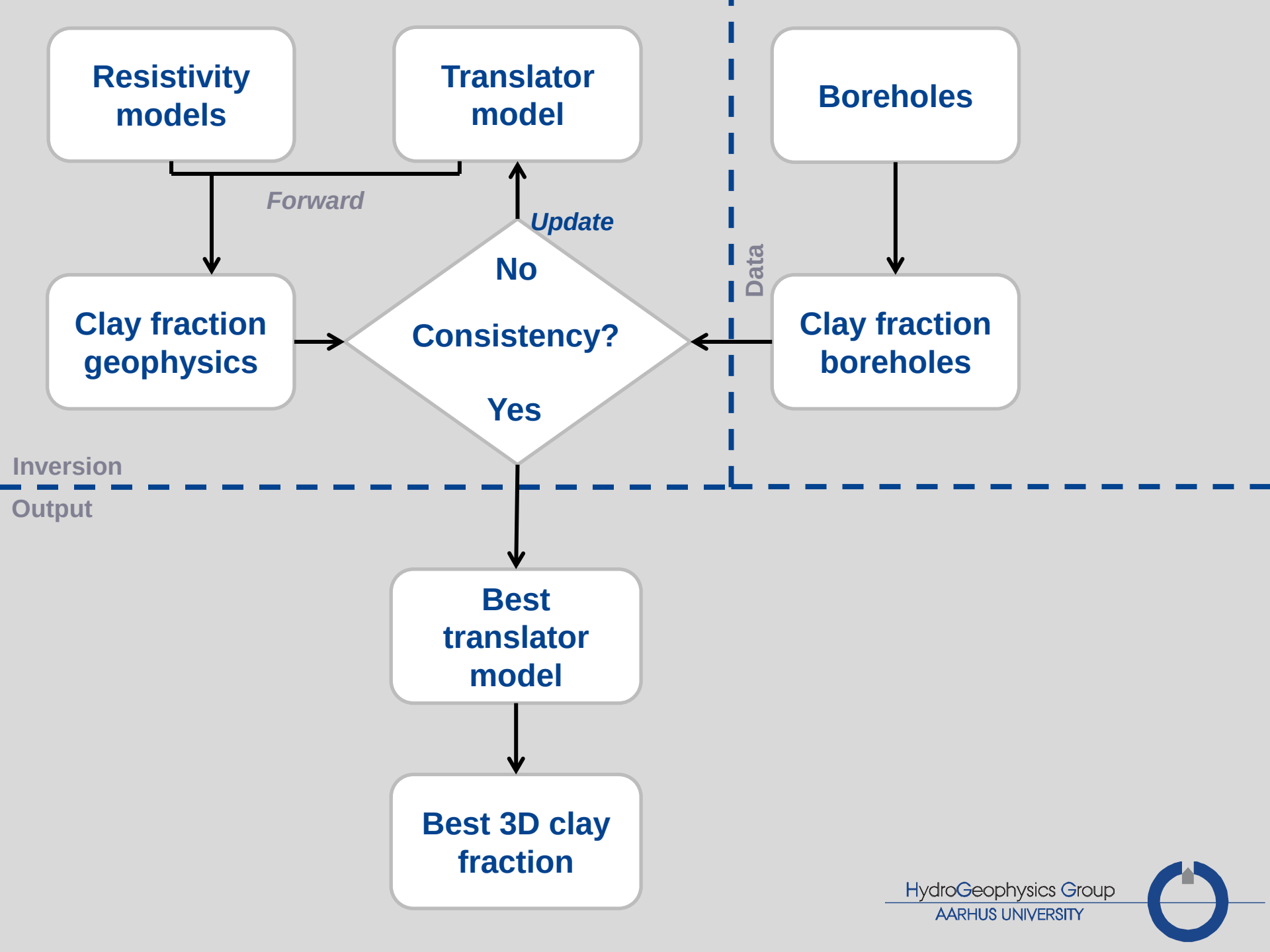


Aim

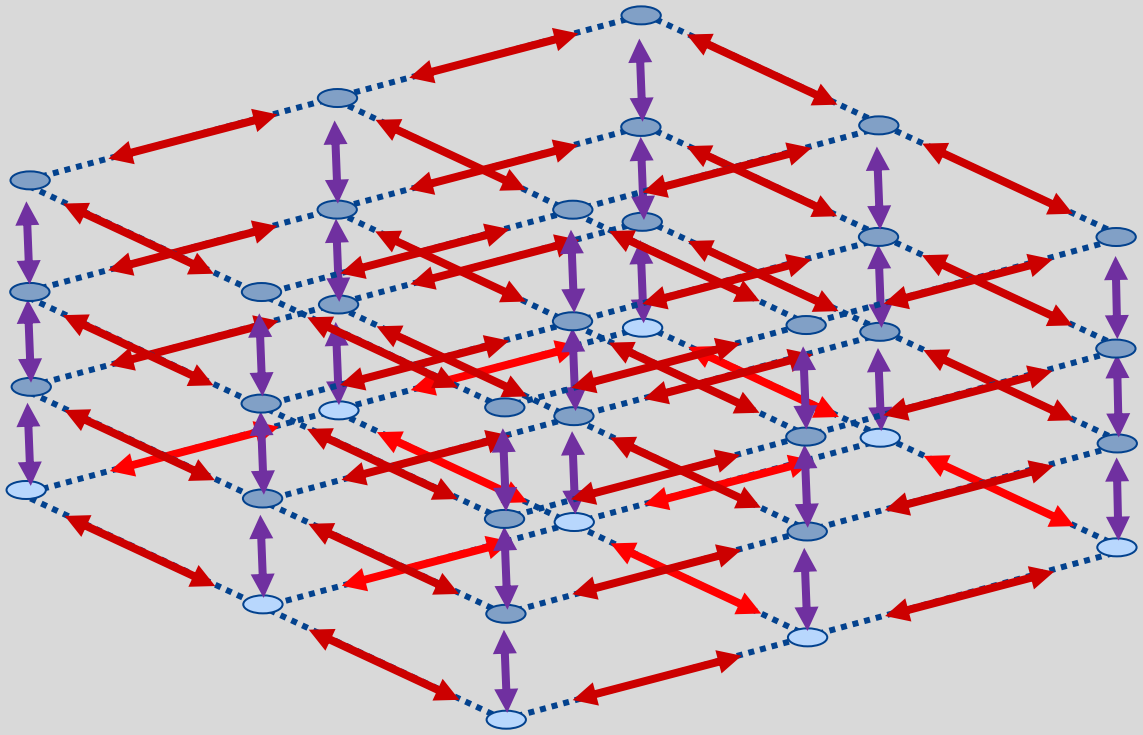
- Obtain consistency between the geophysical clay fraction and the borehole clay fraction

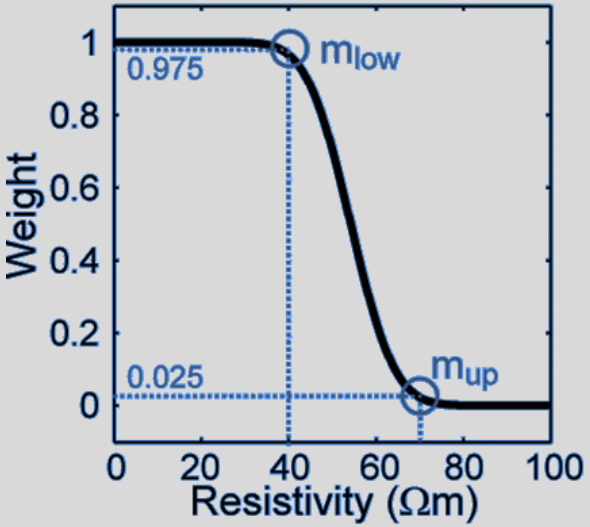
How

- Optimizing the translator model through inversion


Resistivity models
Translator model
Boreholes
Forward
Update
Data
Clay fraction geophysics
No
Consistency?
Yes
Clay fraction boreholes
Inversion
Output
Best translator model
Best 3D clay fraction

Methodology – 3D translator model

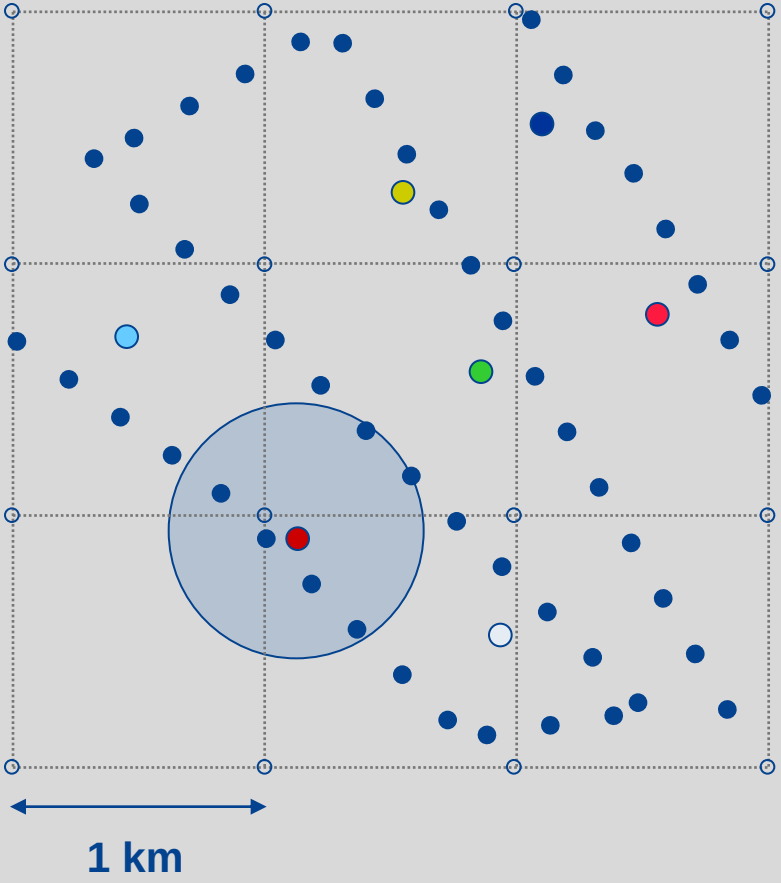




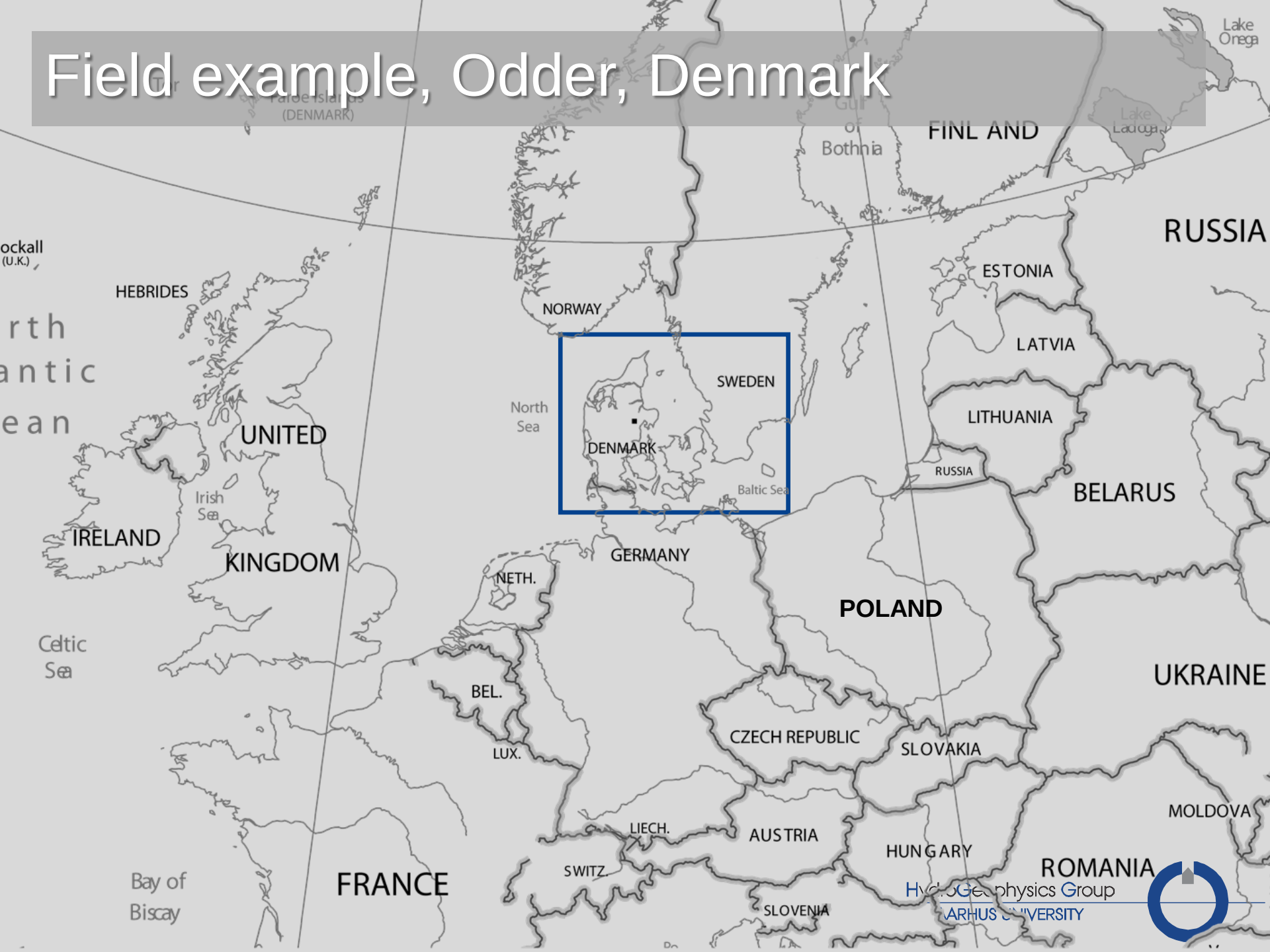
- **Horizontal and vertical constraints (regularization)**

Methodology – Forward and Inversion

- **Evaluation of misfit at the bore hole location**
  - Interpolation by kriging
  - Including uncertainty
- **Iterative least squares inversion**



Field example, Odder, Denmark



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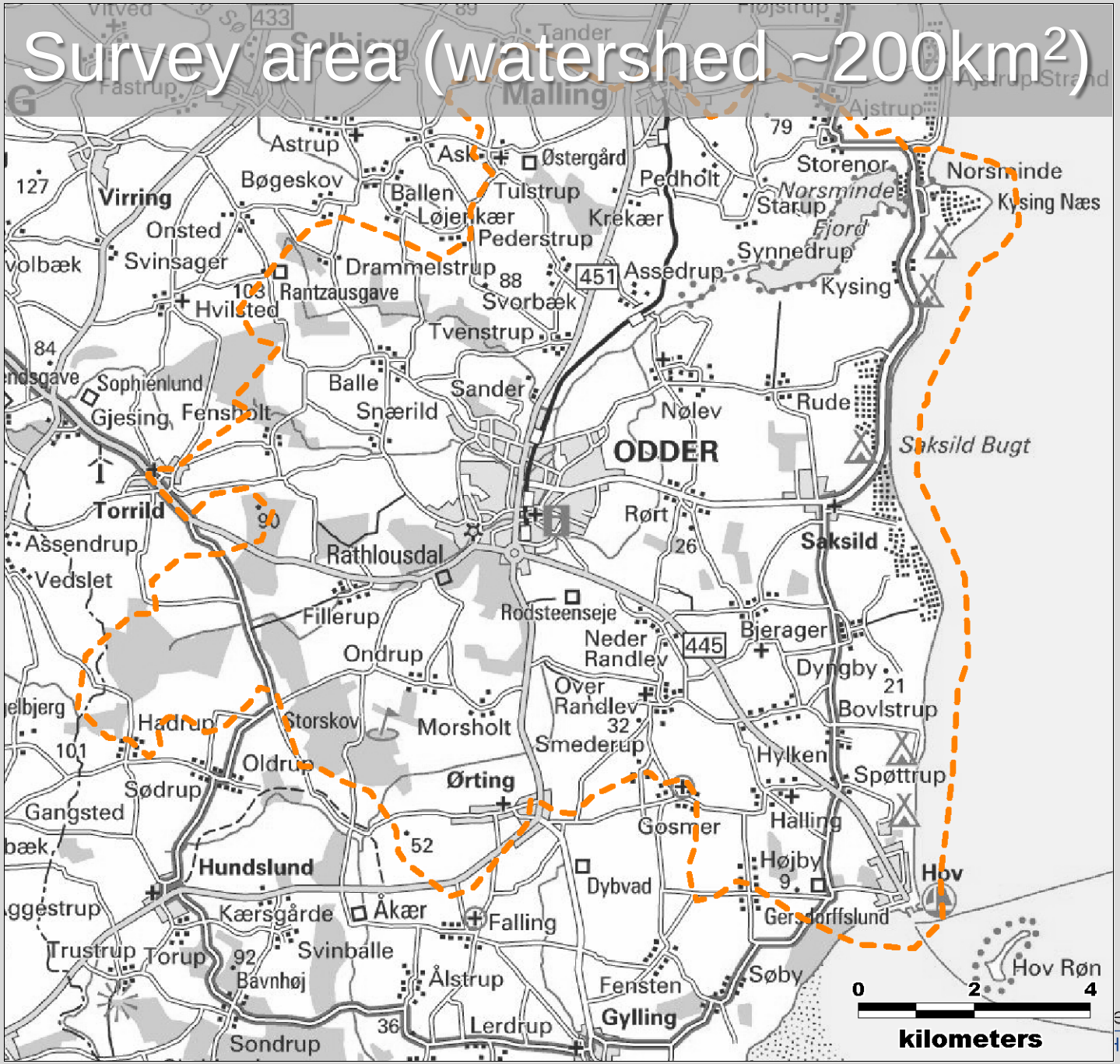
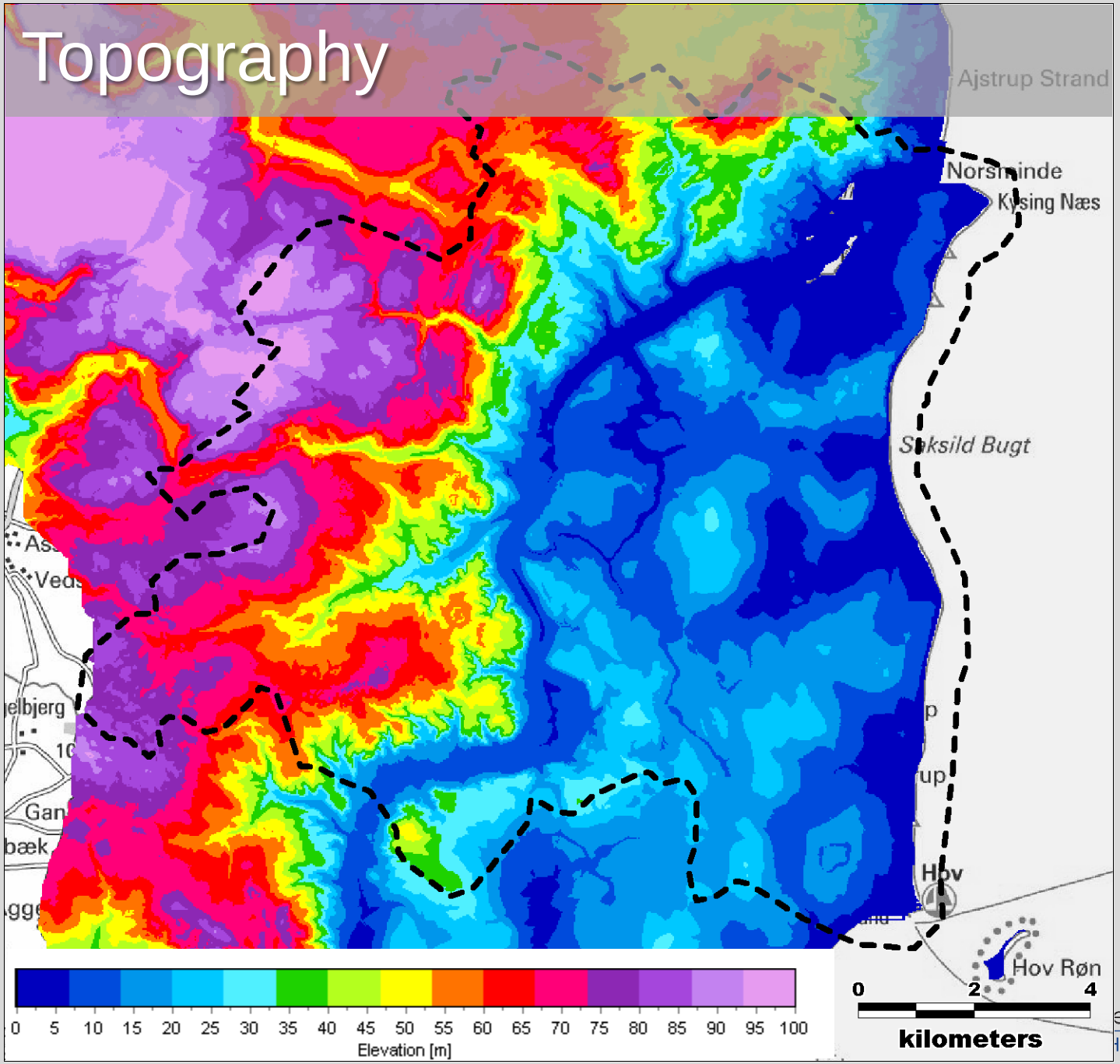
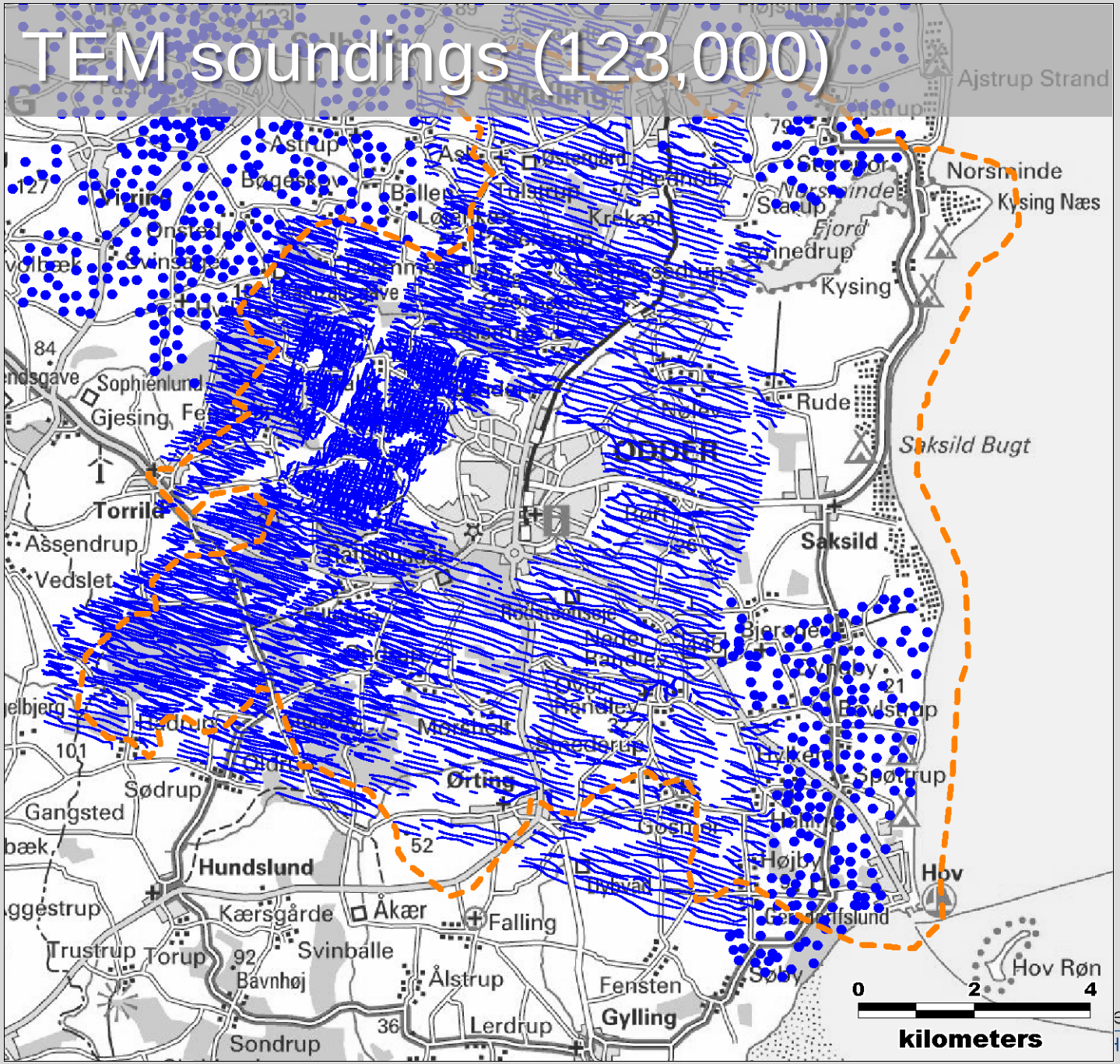
Survey area (watershed ~200km^2)



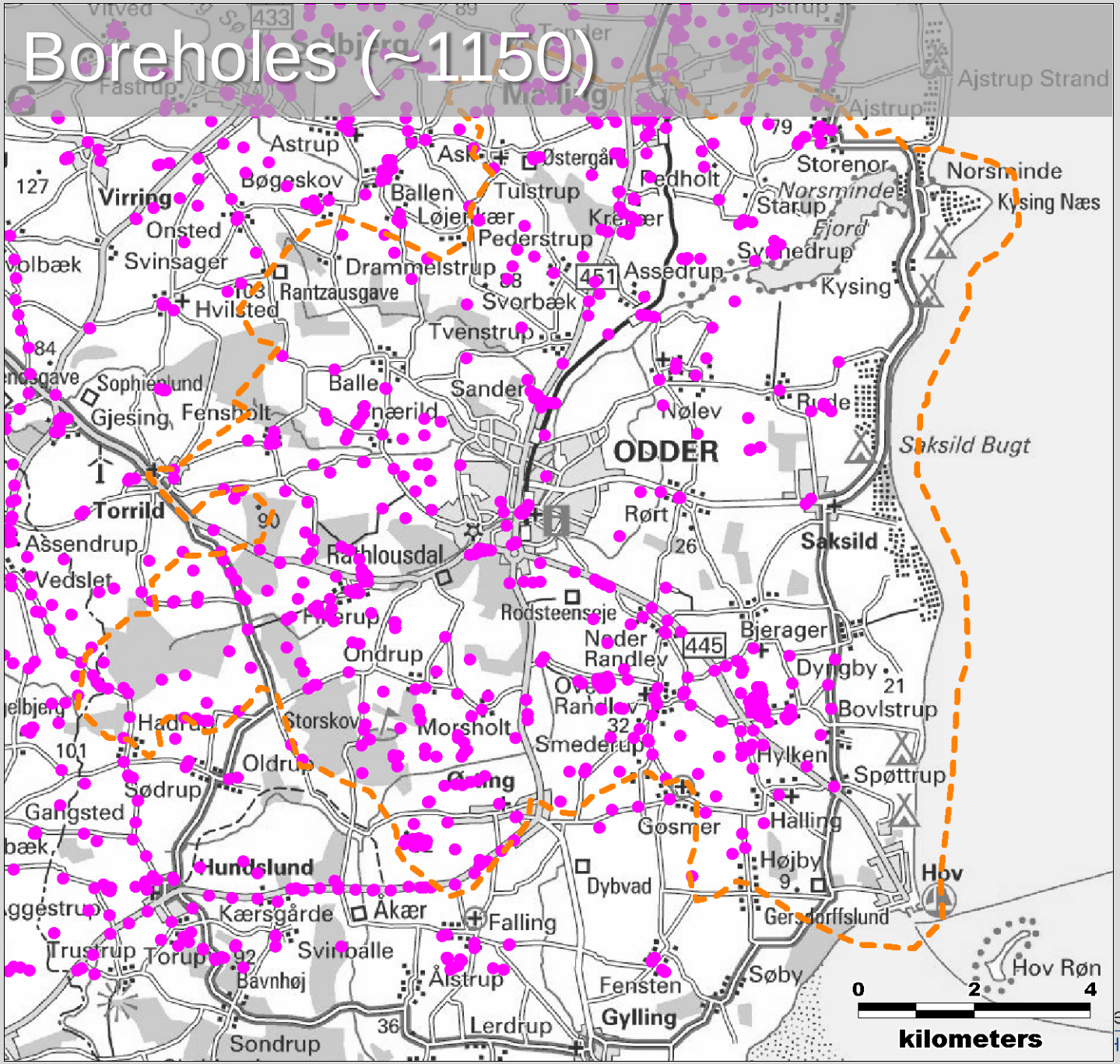
Topography


Ajstrup Strand
Norsminde
Kysing Næs
Stiksild Bugt
Hov
Hov Røn
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Elevation [m]
0 2 4
kilometers

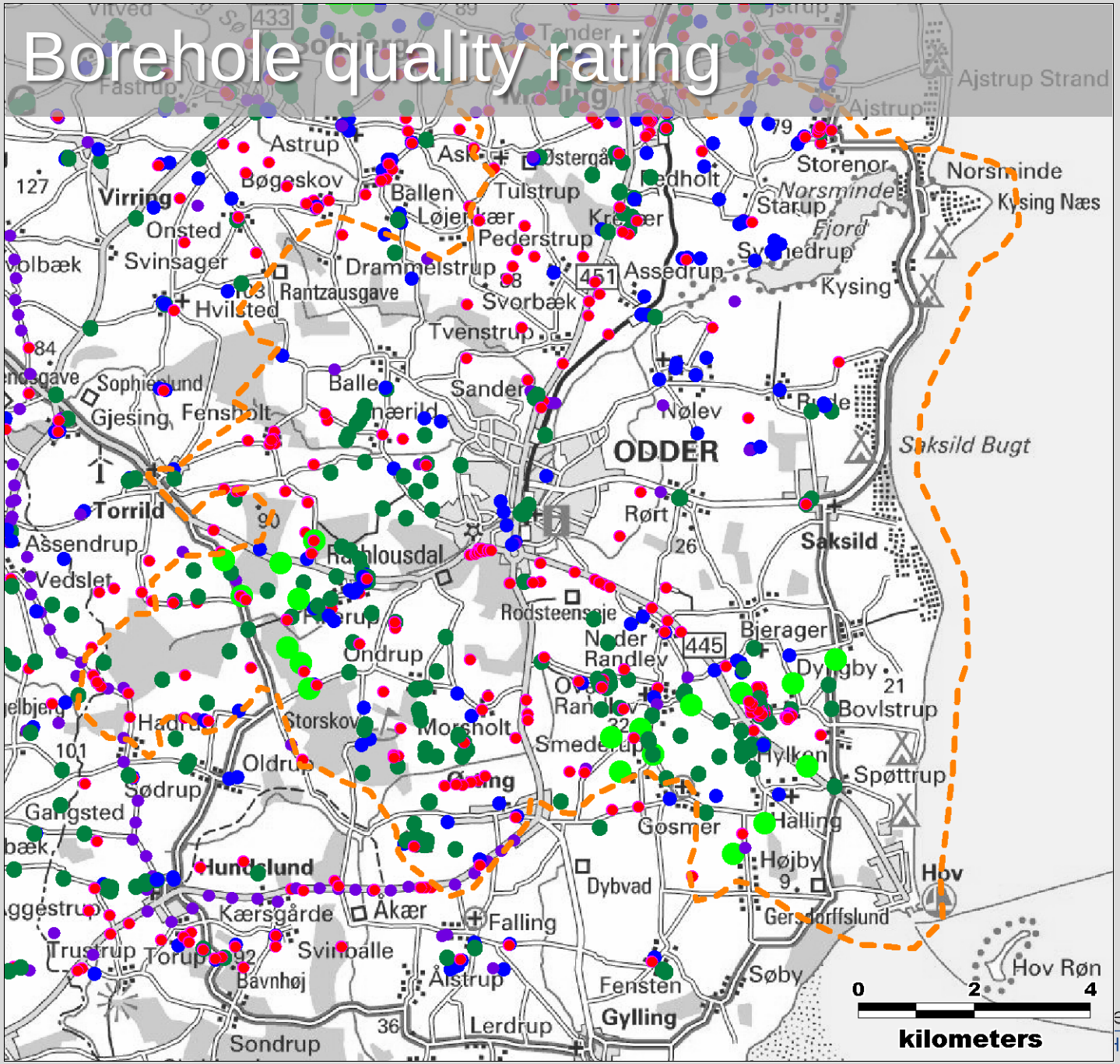
TEM soundings (123,000)



Boreholes (~1150)



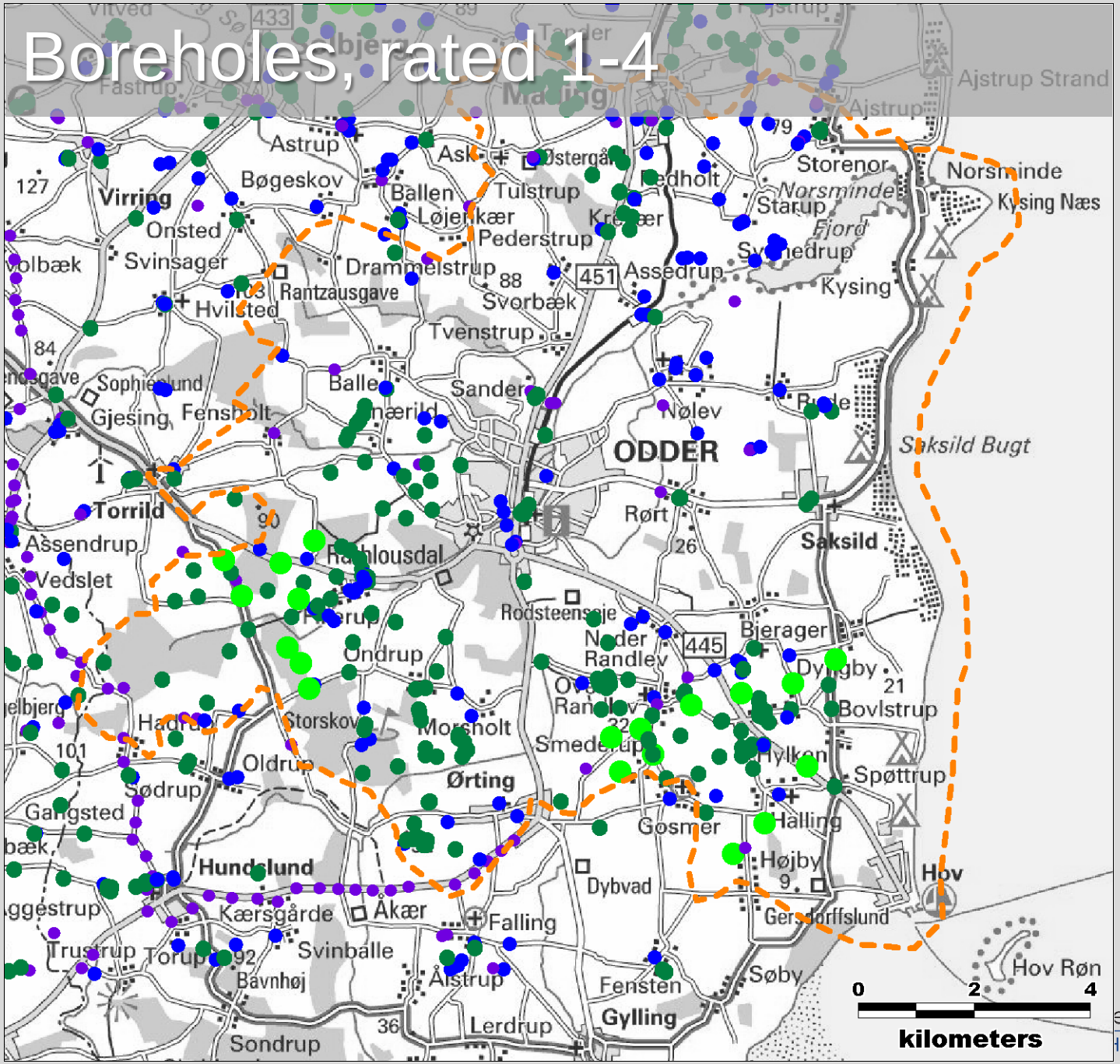
Borehole quality rating



Rating based on:

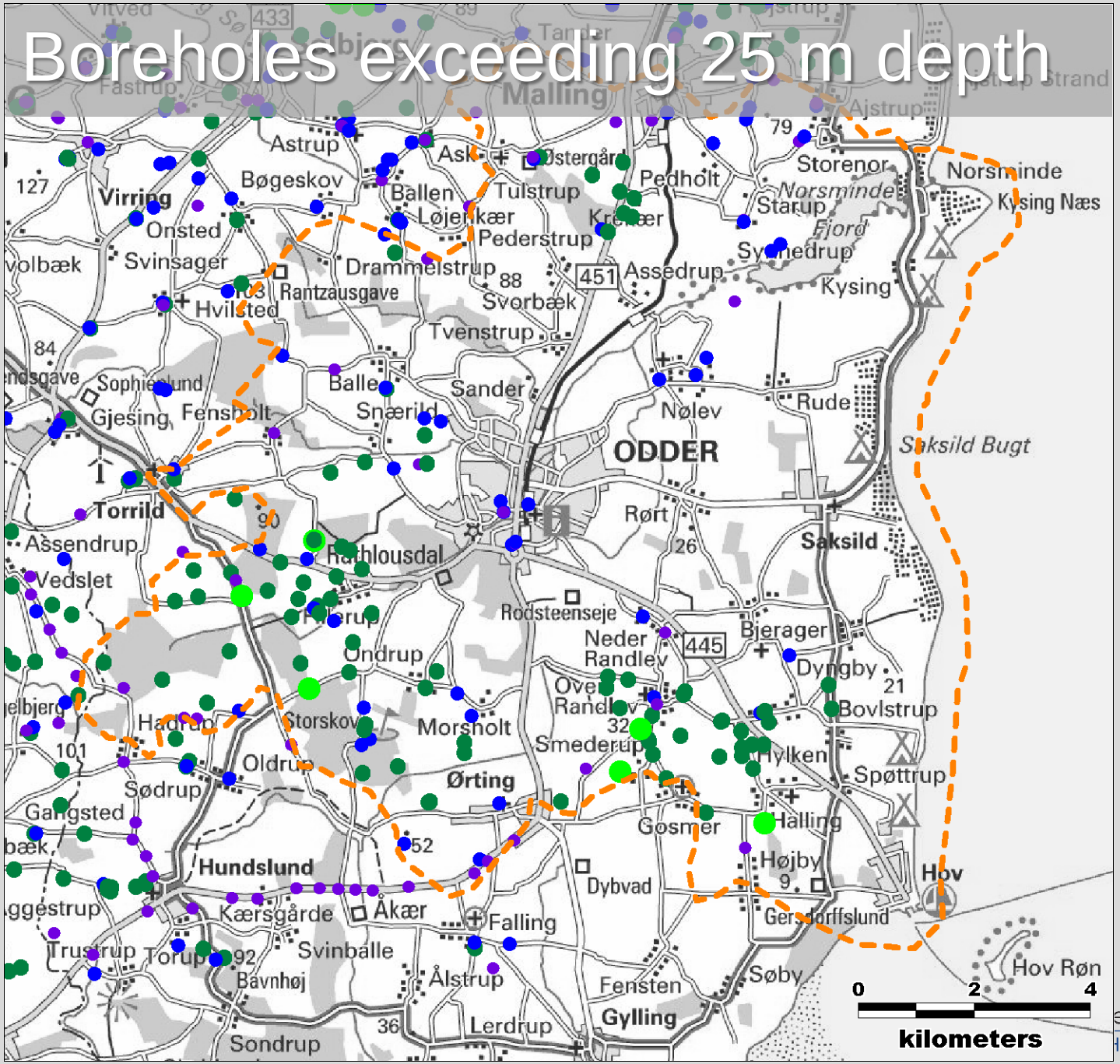
- Age
- Drill method
- Driller
- Drill purpose
- # samples / m
- Sample descrip.

Boreholes, rated 1-4

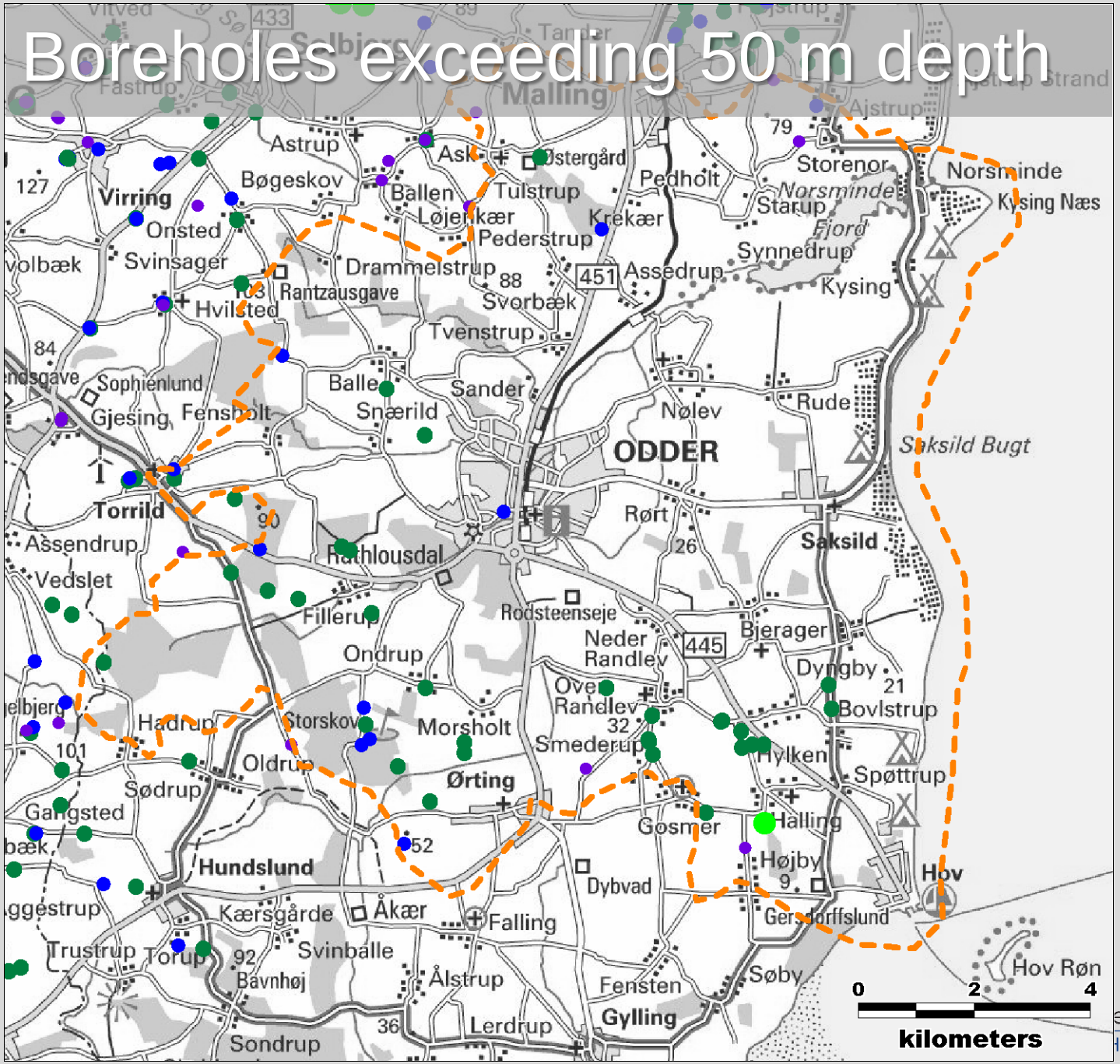


Quality 5 excluded !

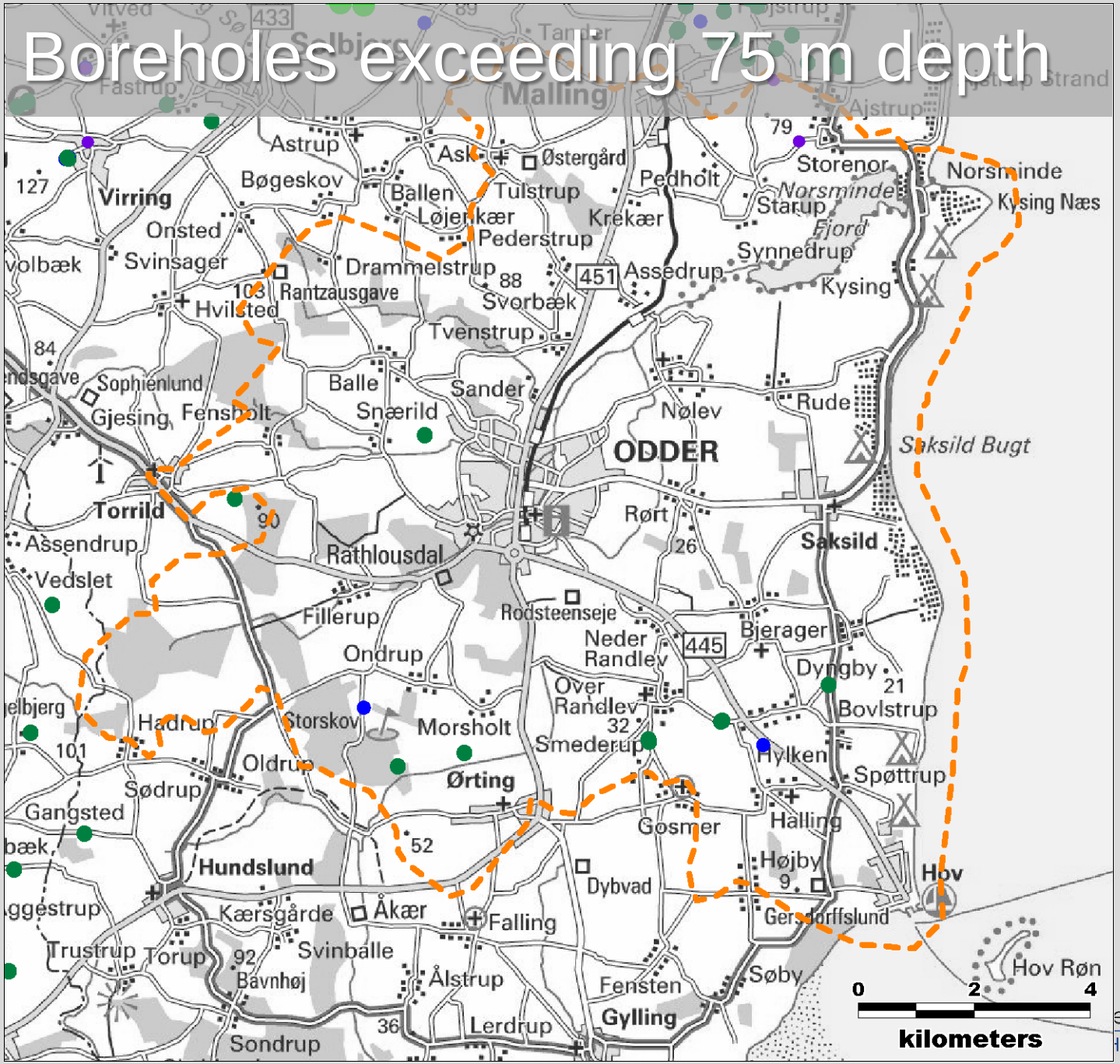
Boreholes exceeding 25 m depth



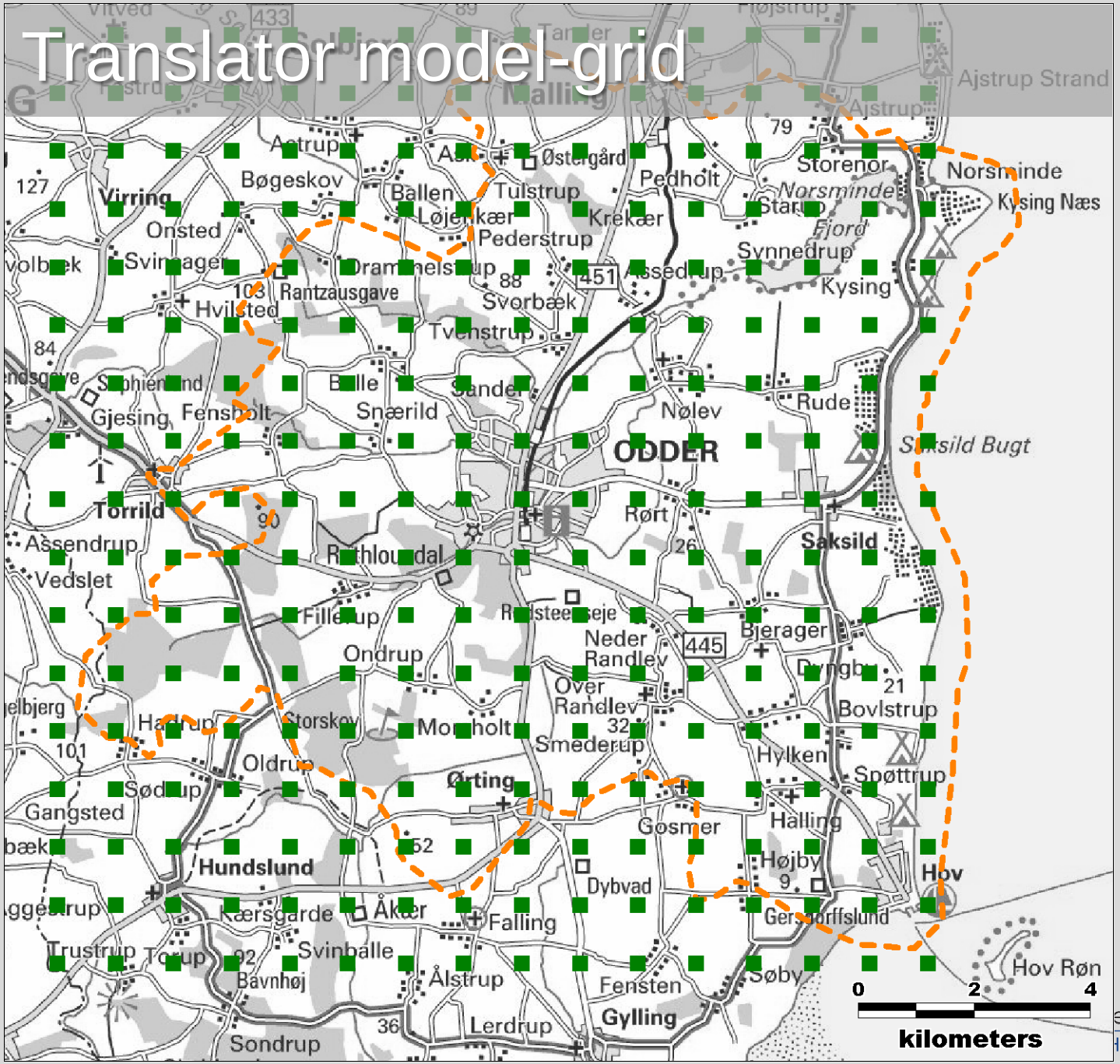
Boreholes exceeding 50 m depth

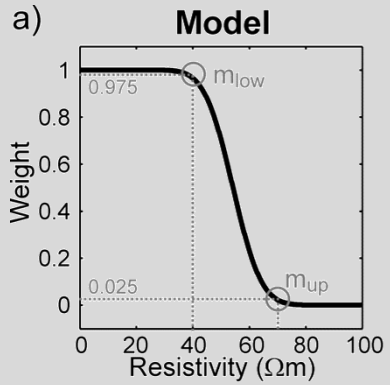


Boreholes exceeding 75 m depth



Translator model-grid



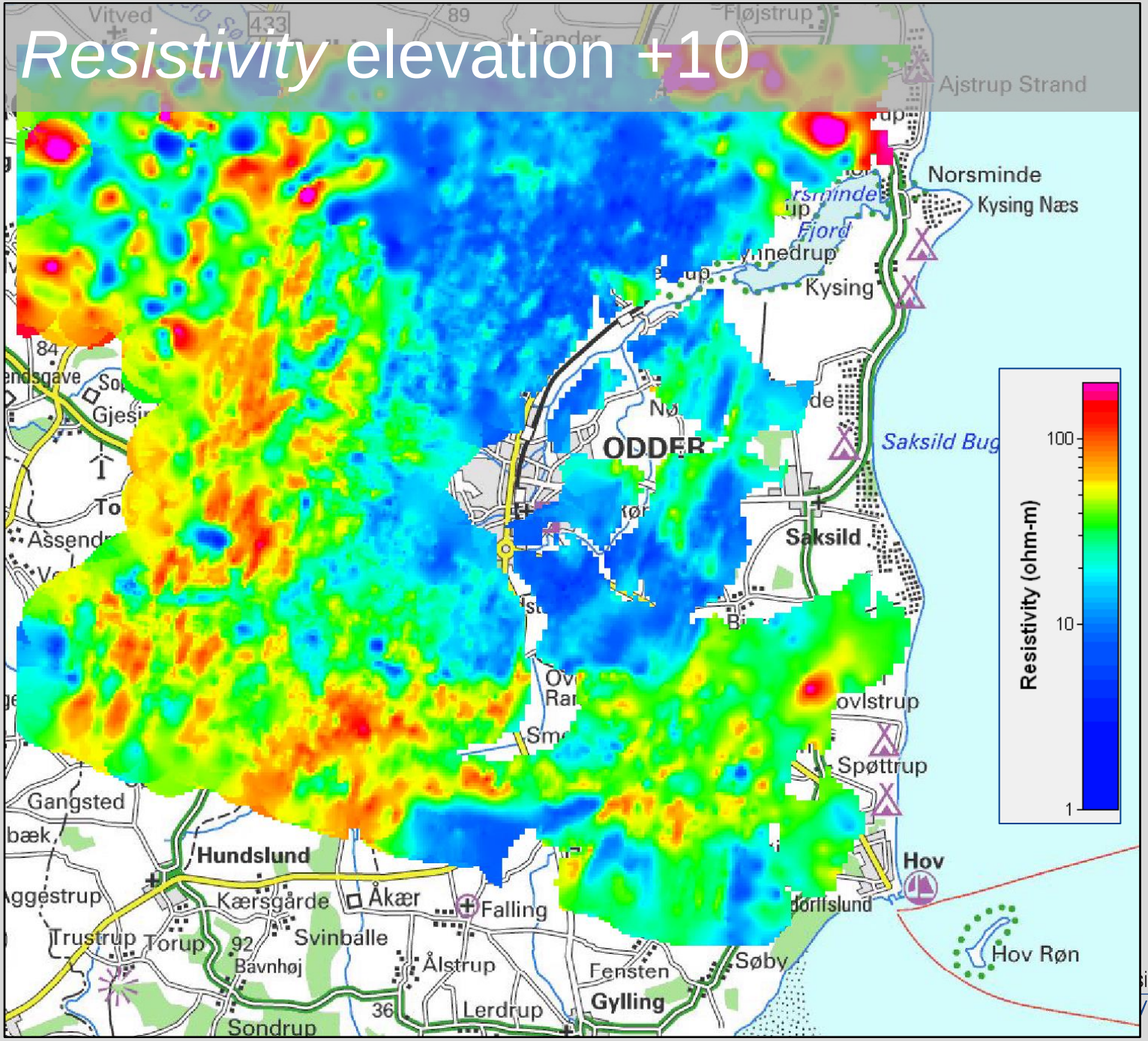


35 layers of:

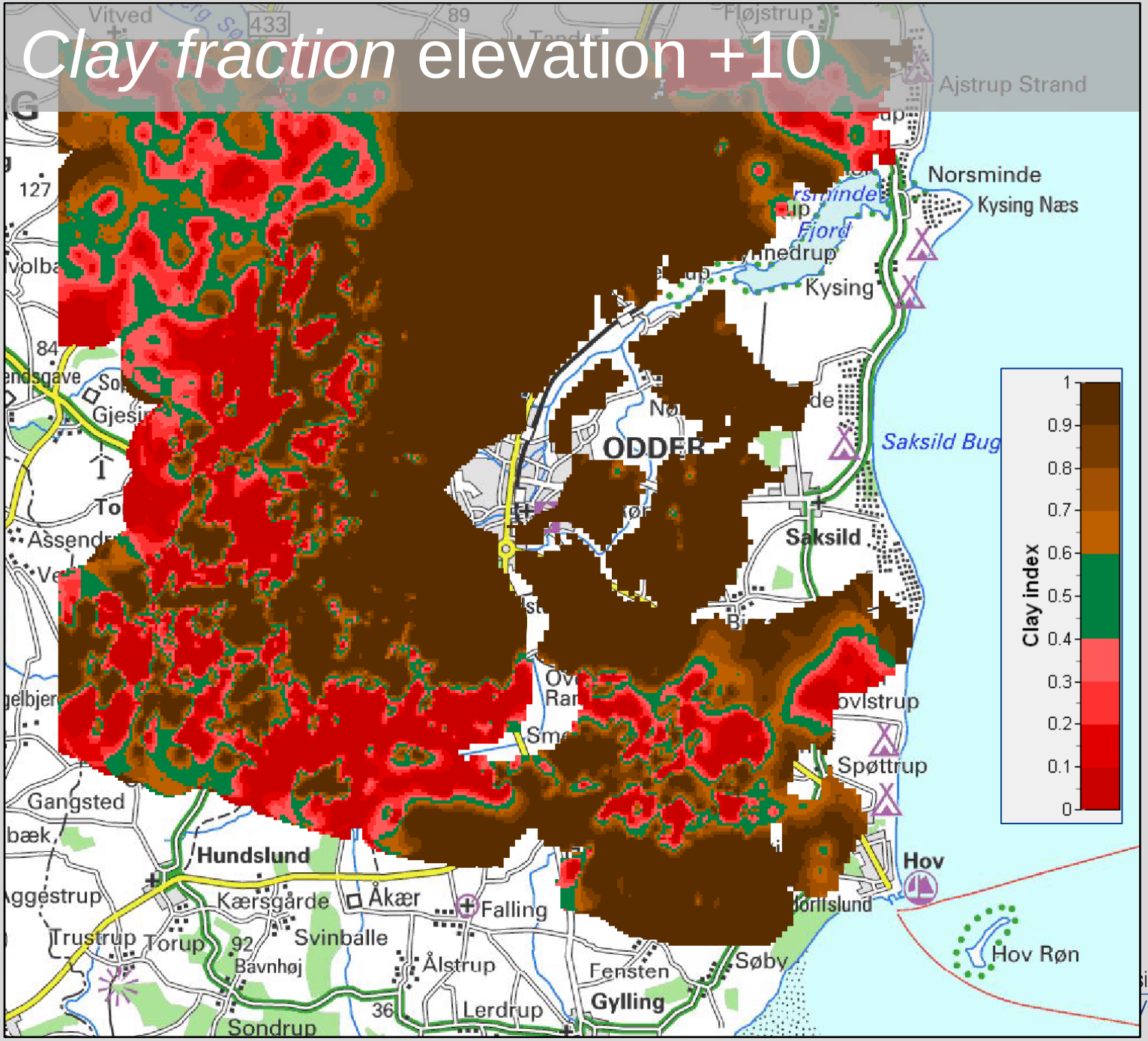
16 x 17 x 2 parameters

= 19040 total

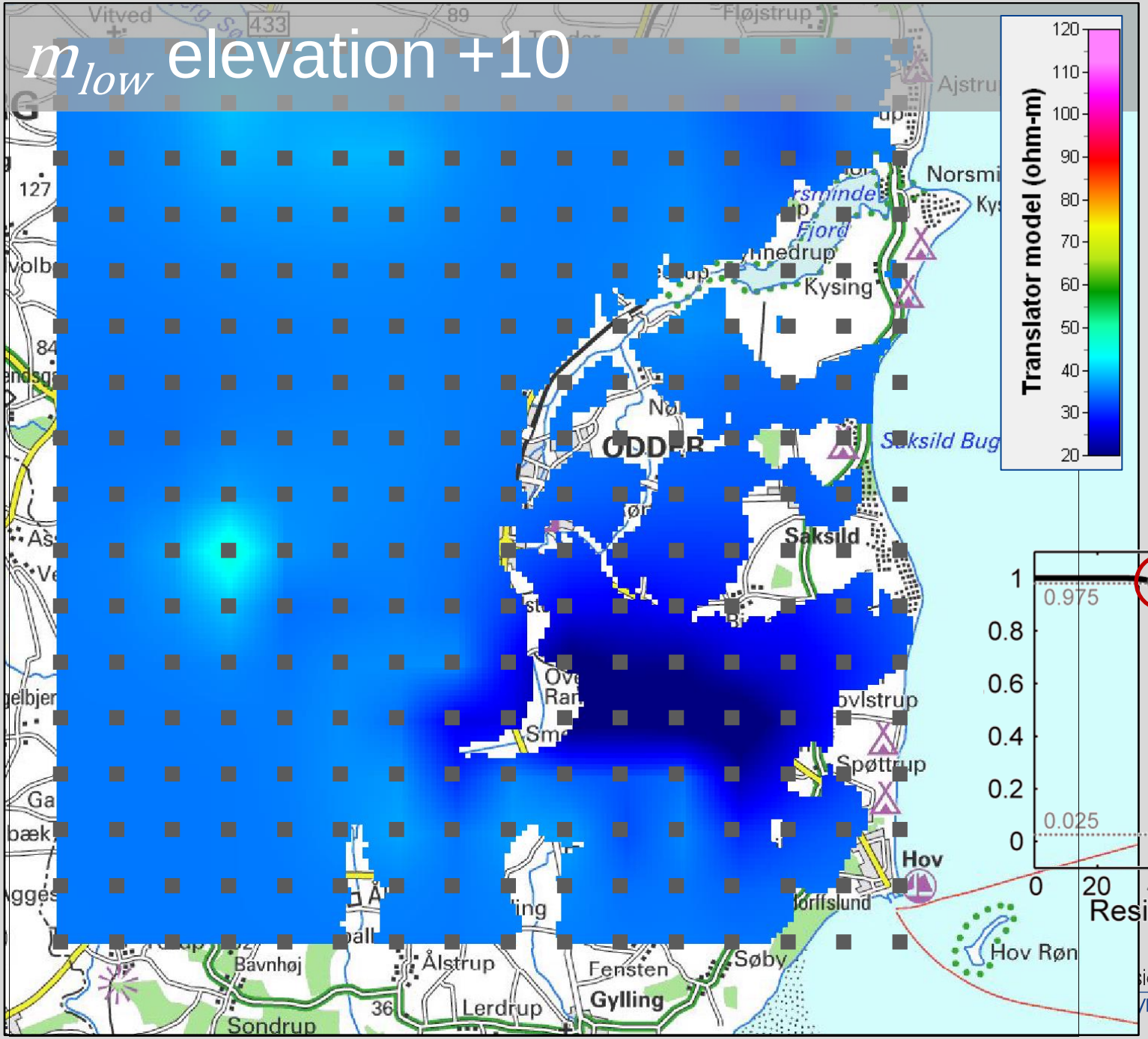
Resistivity elevation +10



Clay fraction elevation +10



m_{low} elevation +10



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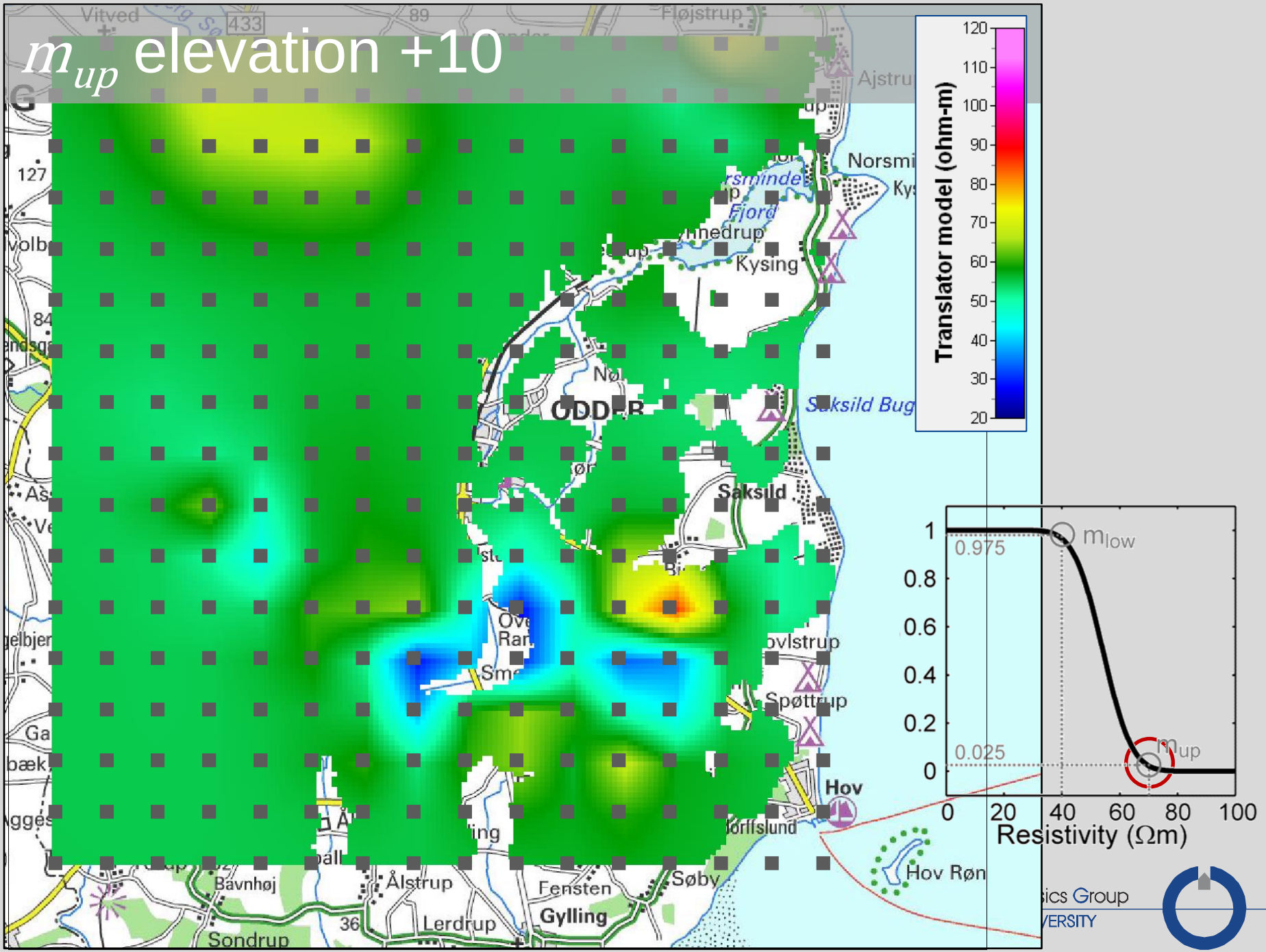
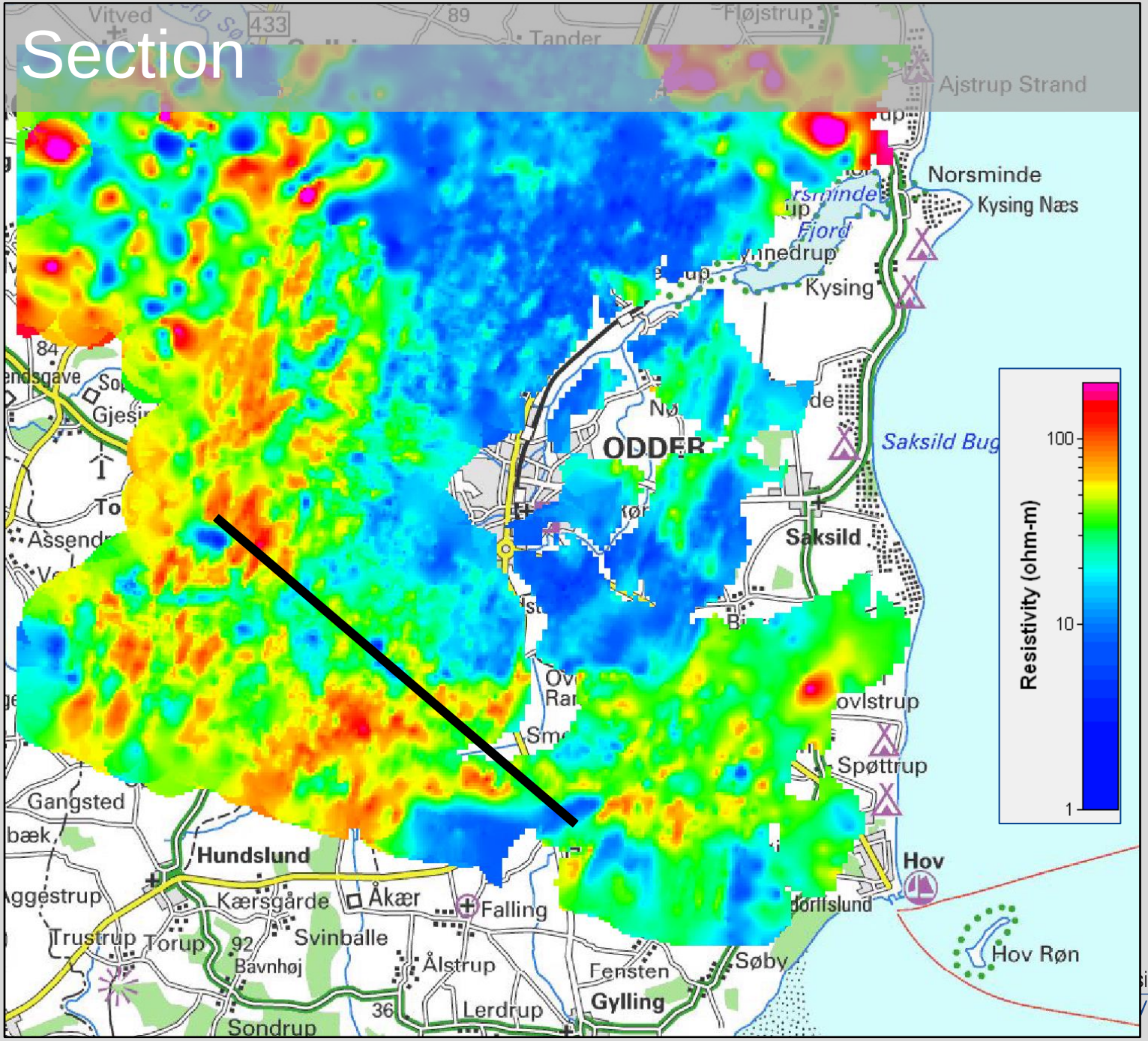
m_{up} elevation +10

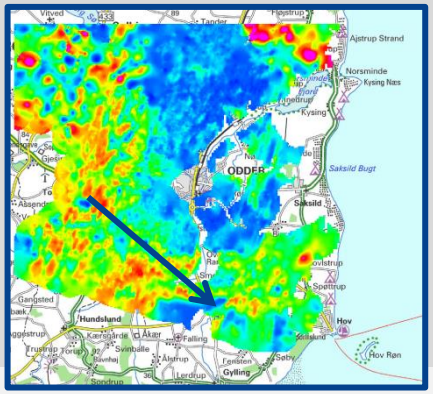


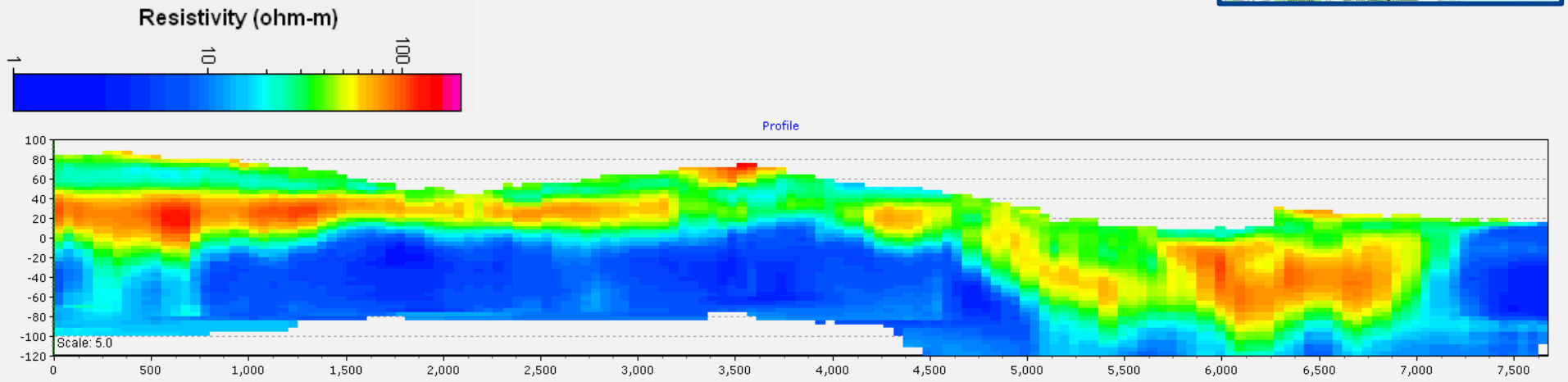
sics Group
VERSITY

Section

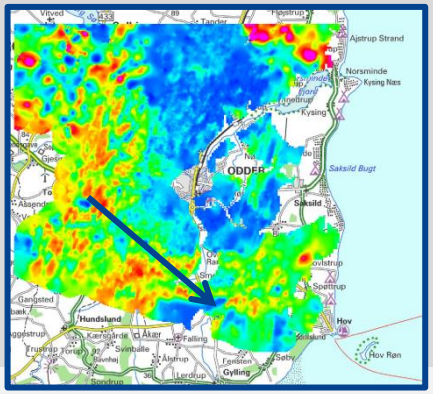

Vitved
433
89
Tander
Fløjstrup
Ajstrup Strand
Norsminde
Kysing Næs
Fjord
Kysing
ODDER
Saksild Bug
Saksild
Spøttrup
Hov
Hov Røn
Gangsted
Hundslund
Kærsgårde
Åkær
Falling
Trustrup
Torup
Svinballe
Bavnhøj
Ålstrup
Fensten
Søby
Gylling
Lerdrup
Sondrup
Resistivity (ohm-m)
100
10
1

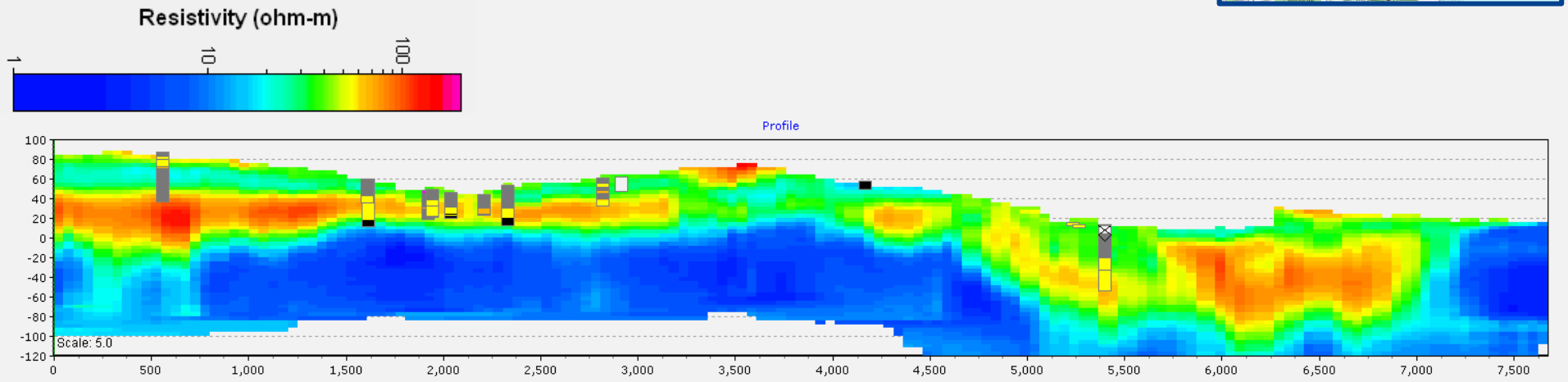
Sections


ODDER
Saksild Bugt
Hundslund
Gylling


Resistivity (ohm-m)
1
10
100
Profile
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
Scale: 5.0
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
5,000
5,500
6,000
6,500
7,000
7,500

Sections


ODDER
Saksild Bugt
Hundslund
Gylling


Resistivity (ohm-m)
1
10
100
Profile
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
Scale: 5.0
0
500
1,000
1,500
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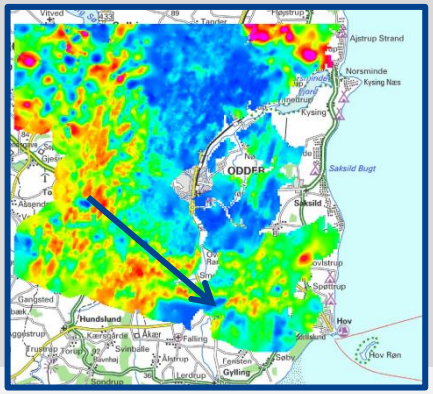
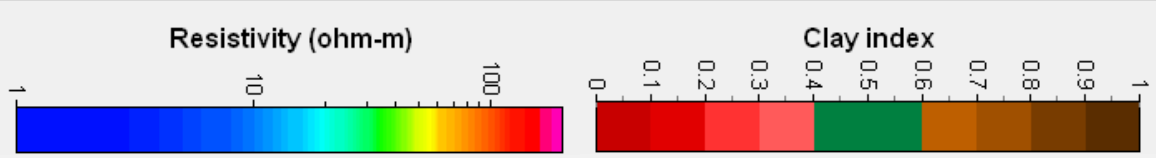
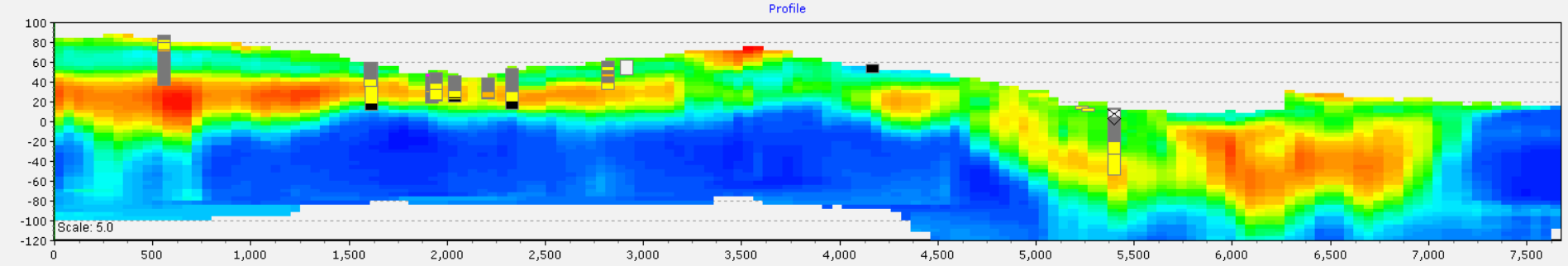
6,500
7,000
7,500

Sections


ODDER
Saksild Bugt
Hundslund
Gylling


Resistivity (ohm-m)
1
10
100
Clay index
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Profile
Scale: 5.0
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
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500
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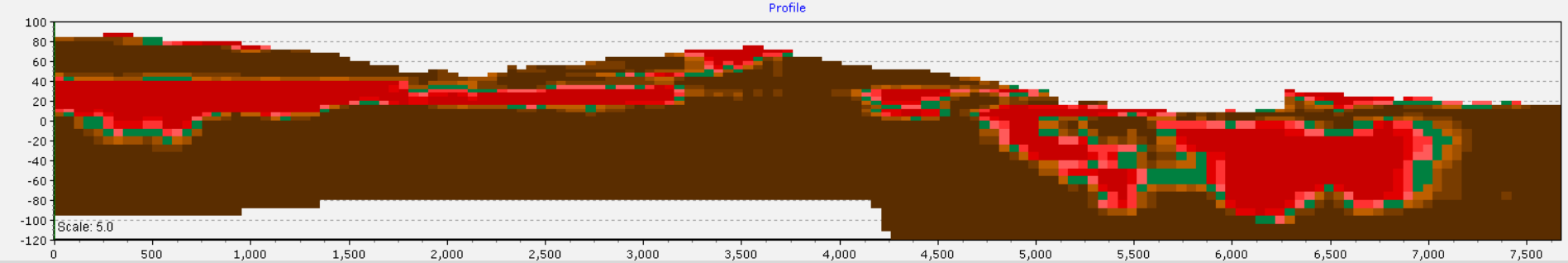
Profile
Scale: 5.0
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-60
-80
-100
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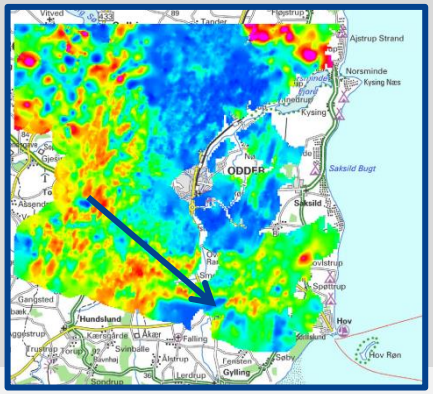
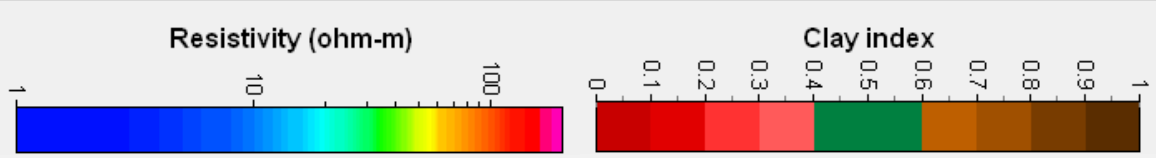
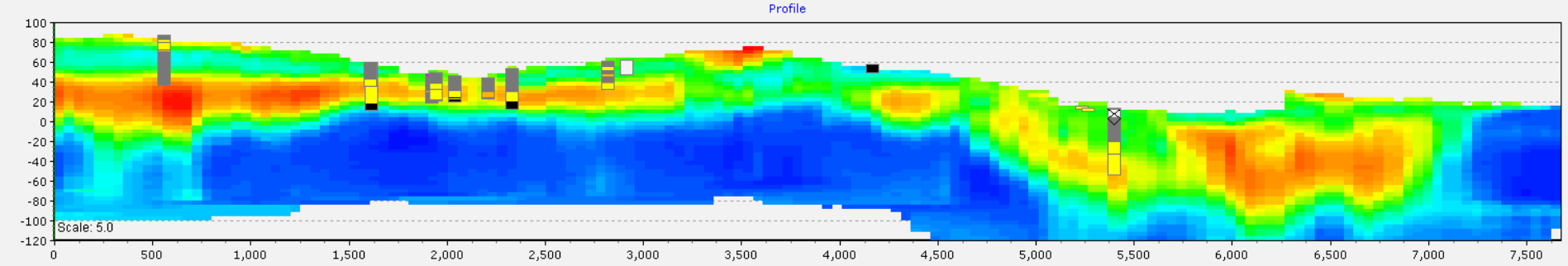
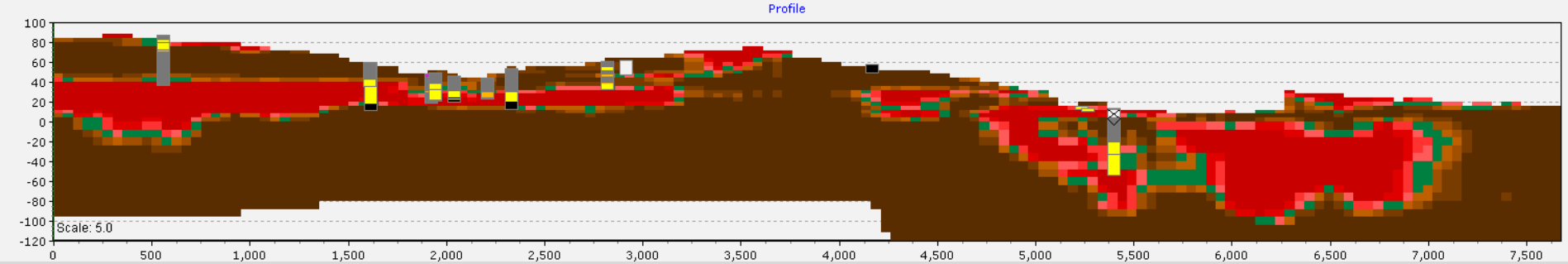
6,500
7,000
7,500

Sections









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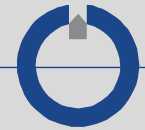
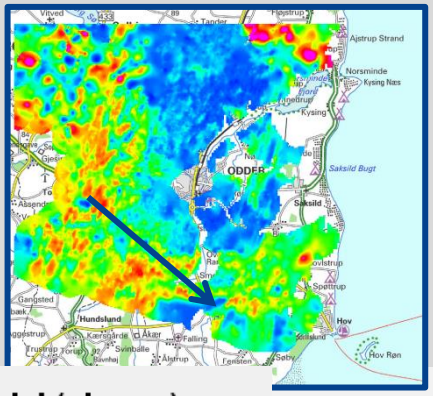
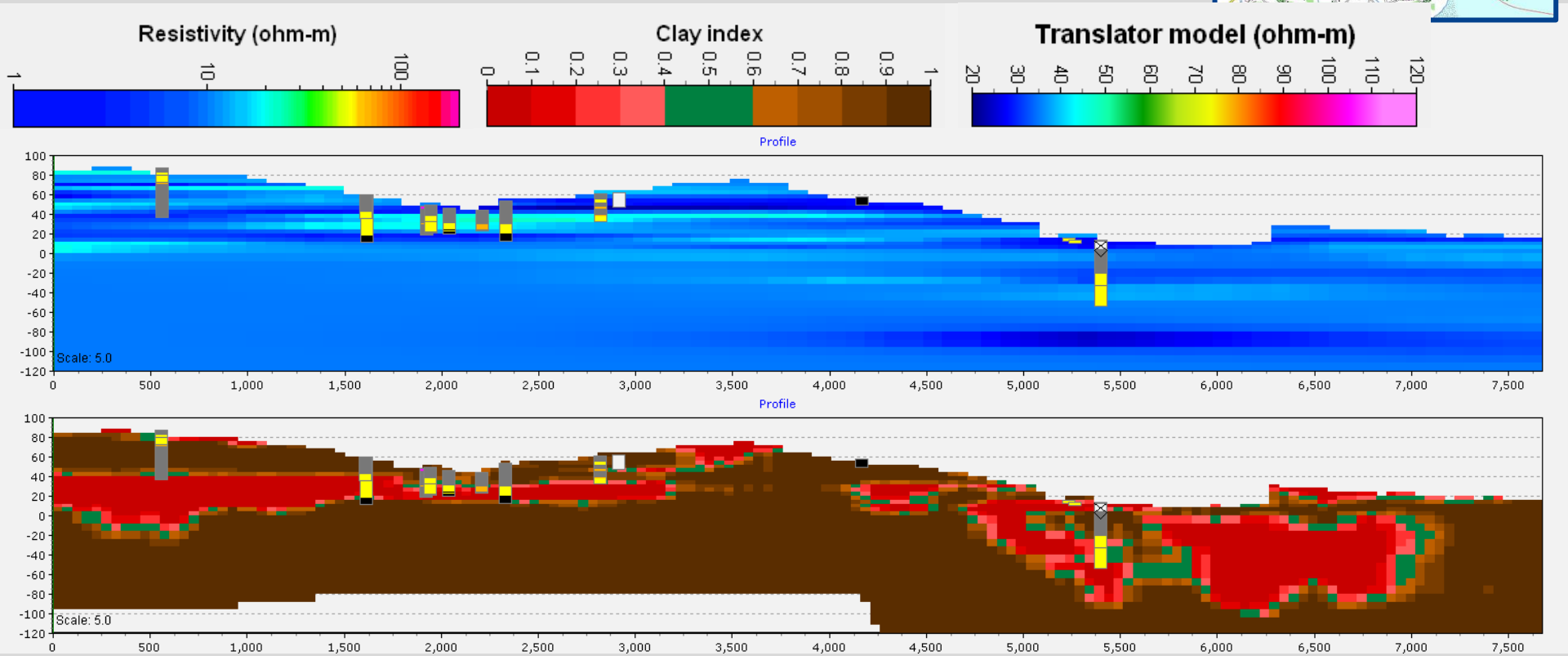


Sections





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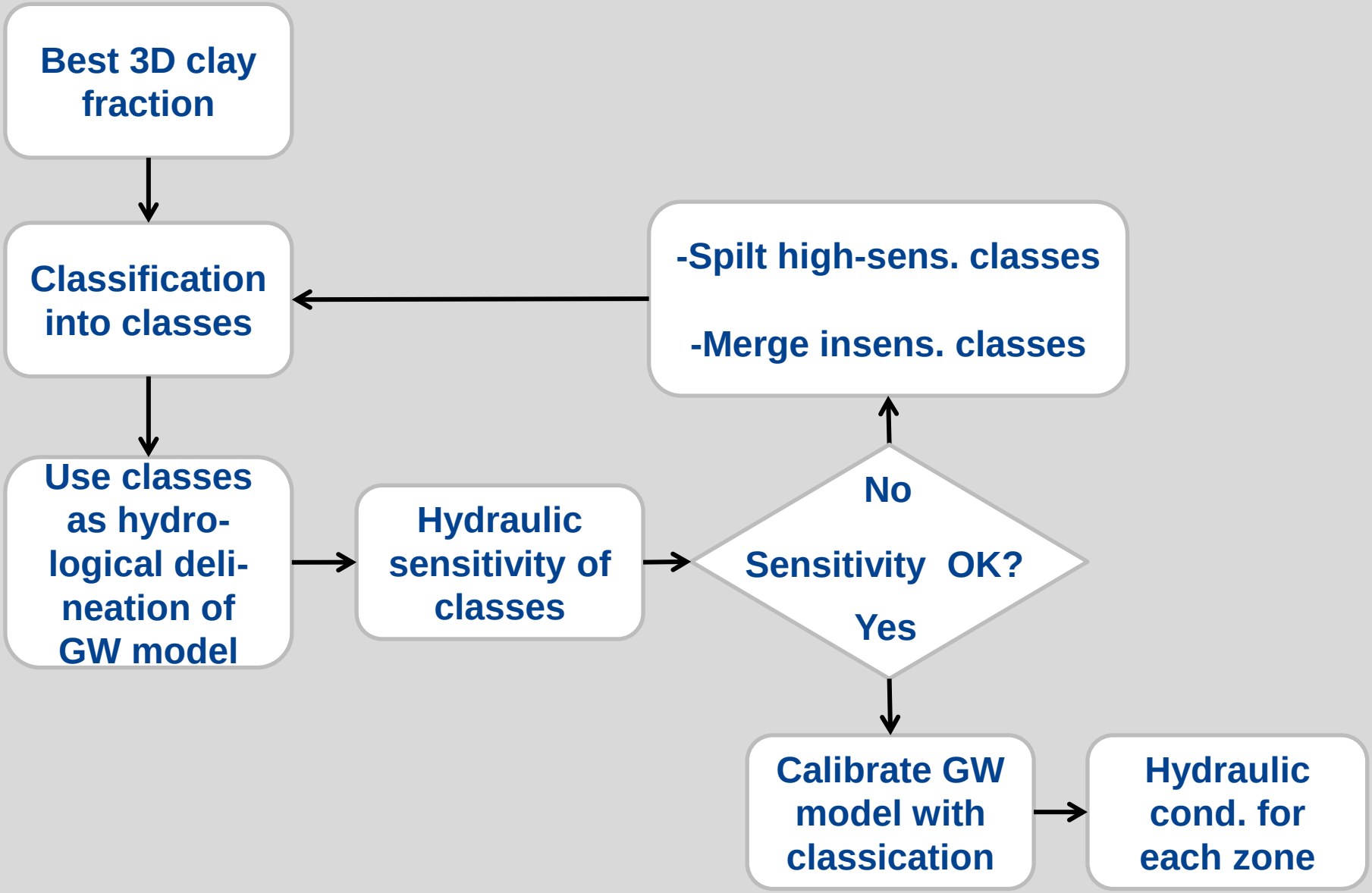
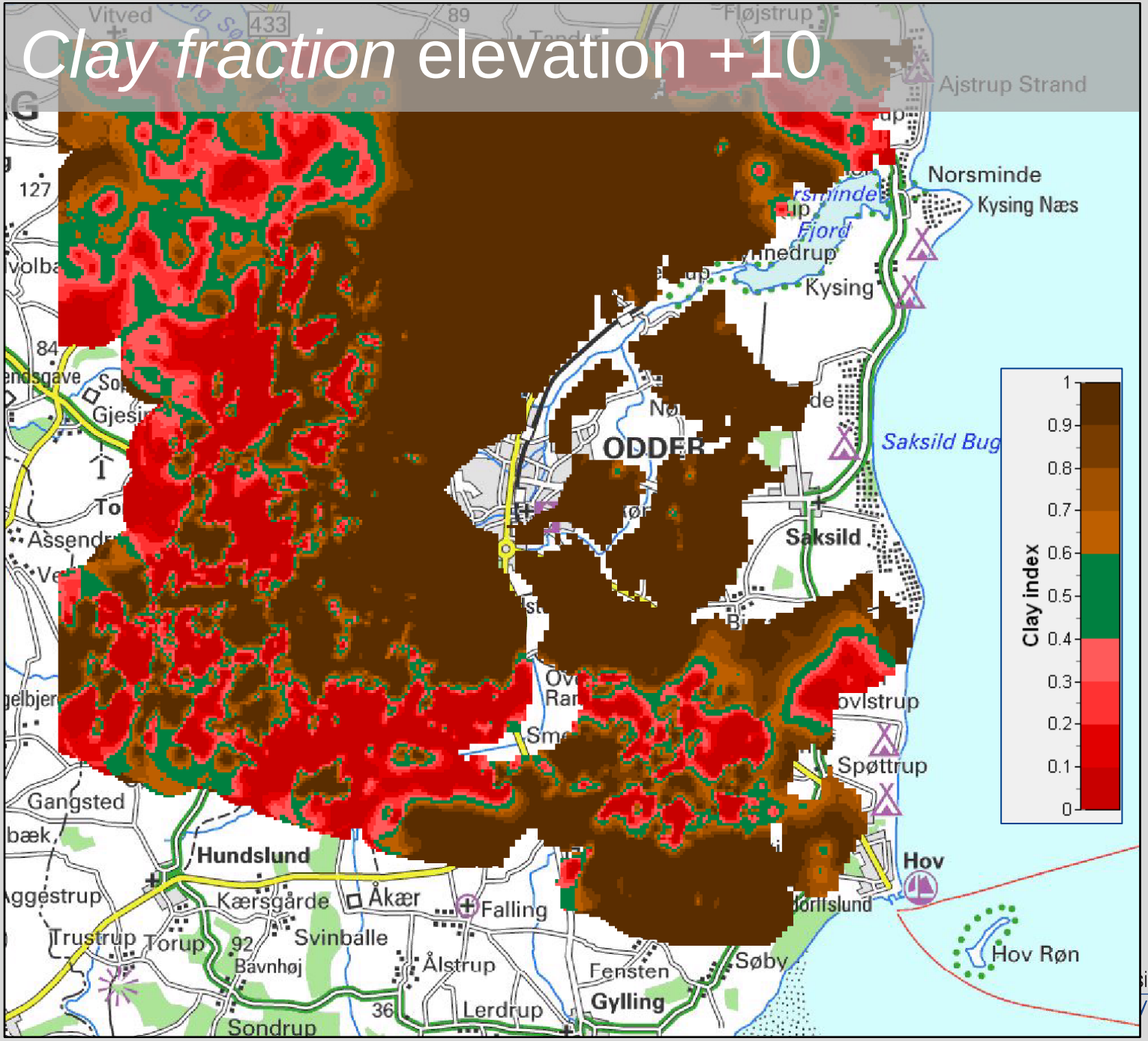
Methodology – Part 2; Classification

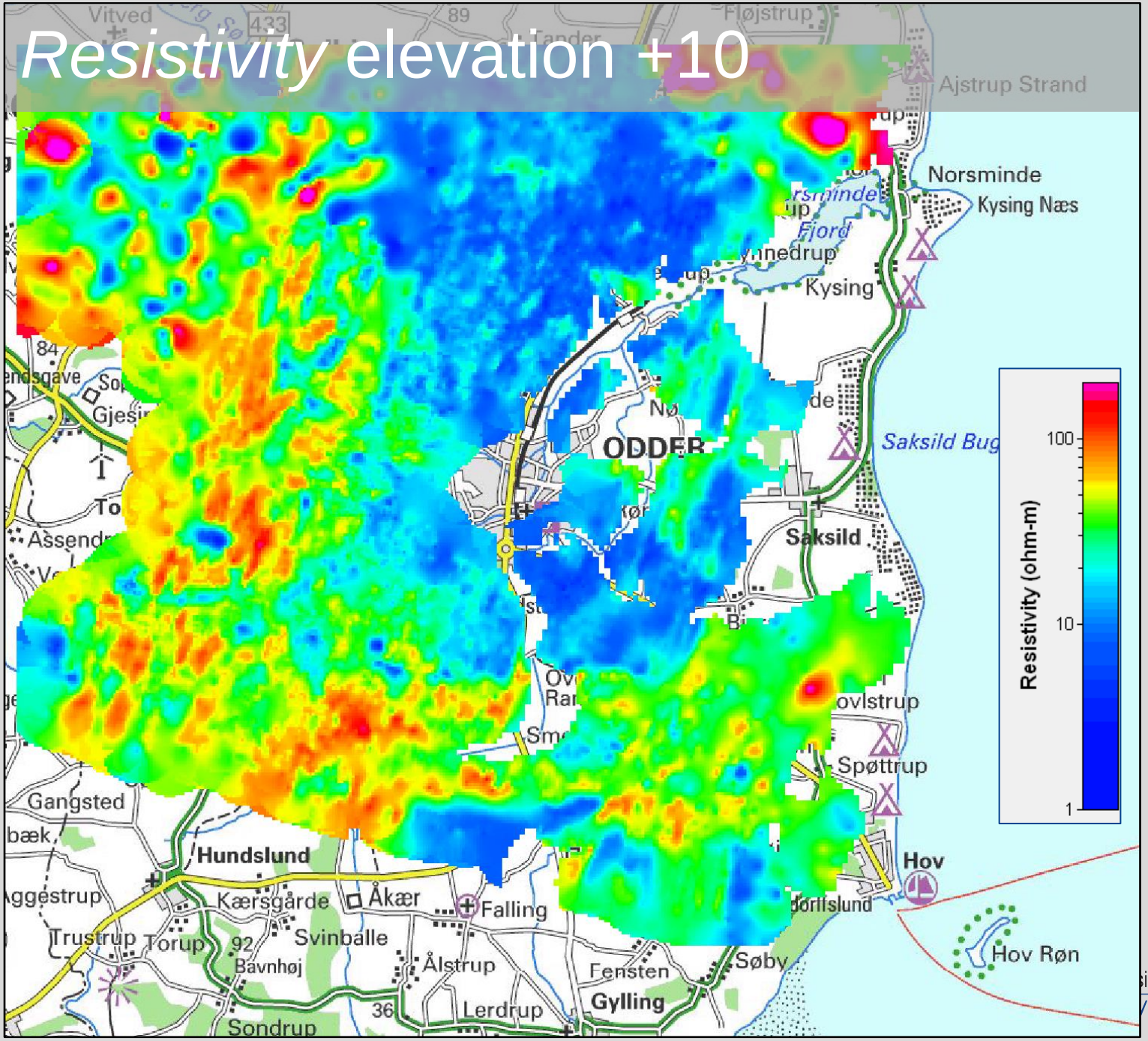
- **Postulate:**
  - Patterns in parameters can be interpreted as patterns in K
- **K-means classification on principal components (PCA) of**
  - 3D Resistivity grid
  - 3D clay-fraction model
- **Other possible parameters**
  - Translator model
  - A priori geological information (regional divisions)
  - Soil maps
- **Classification output**
  - 4 classes sought (probably enough for the GW model)


Best 3D clay fraction
Classification into classes
-Spilt high-sens. classes
-Merge insens. classes
Use classes as hydro-logical deli-neation of GW model
Hydraulic sensitivity of classes
No
Sensitivity OK?
Yes
Calibrate GW model with classication
Hydraulic cond. for each zone

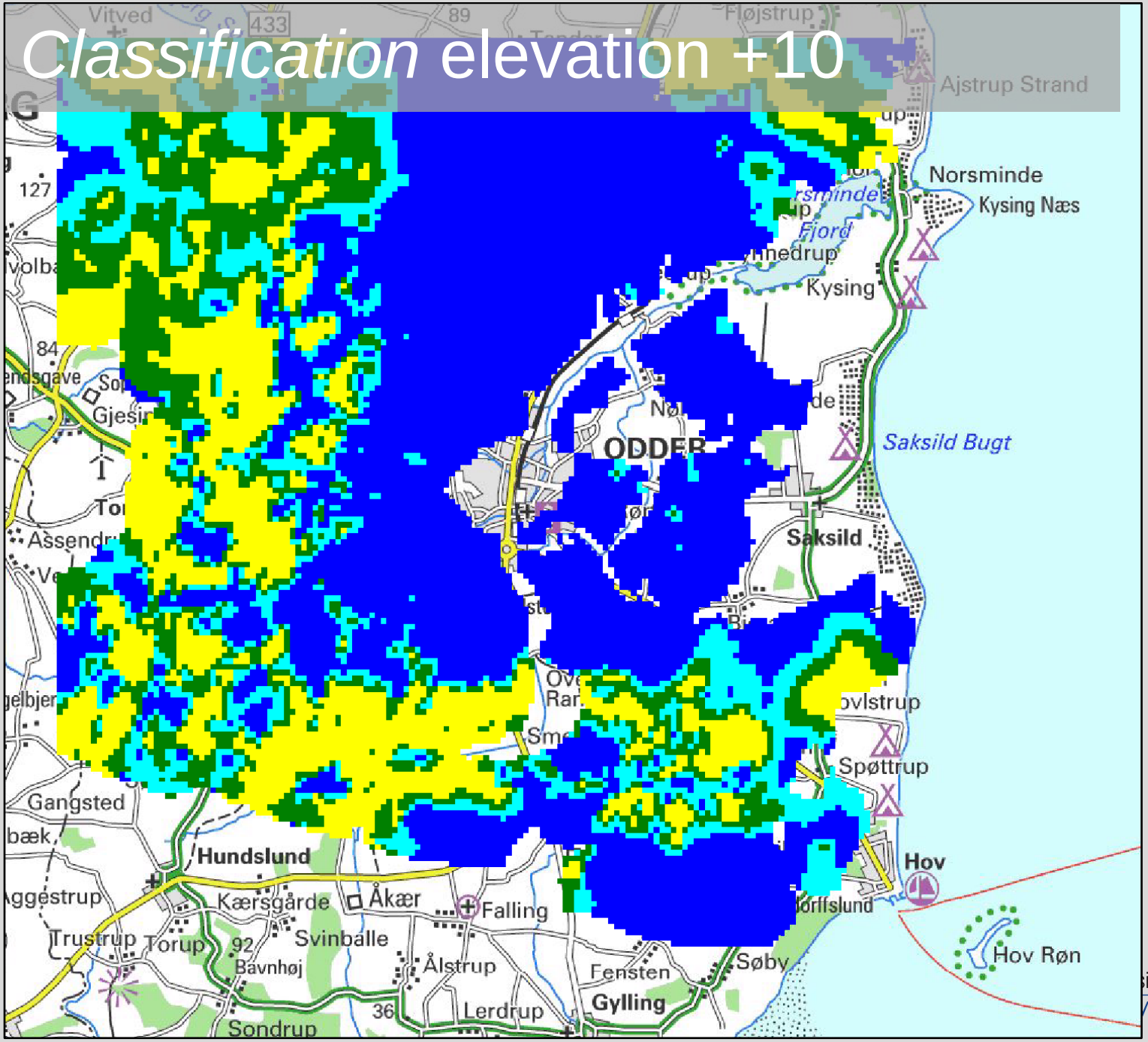
Clay fraction elevation +10



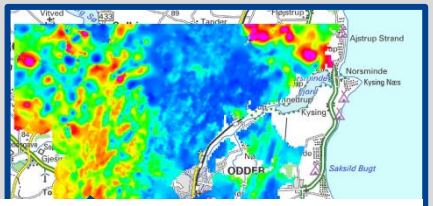
Resistivity elevation +10

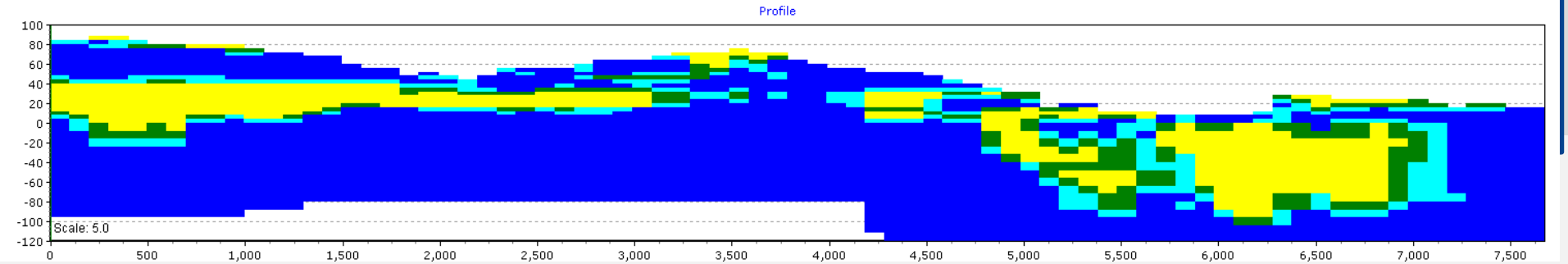


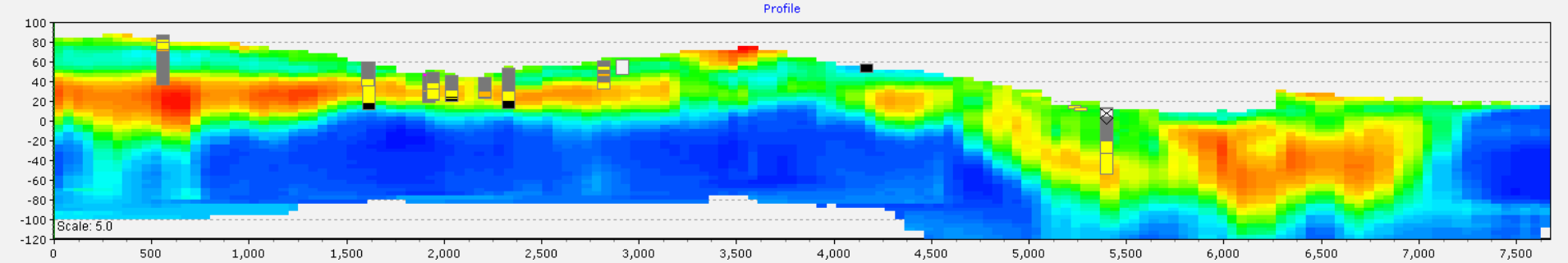
Classification elevation +10

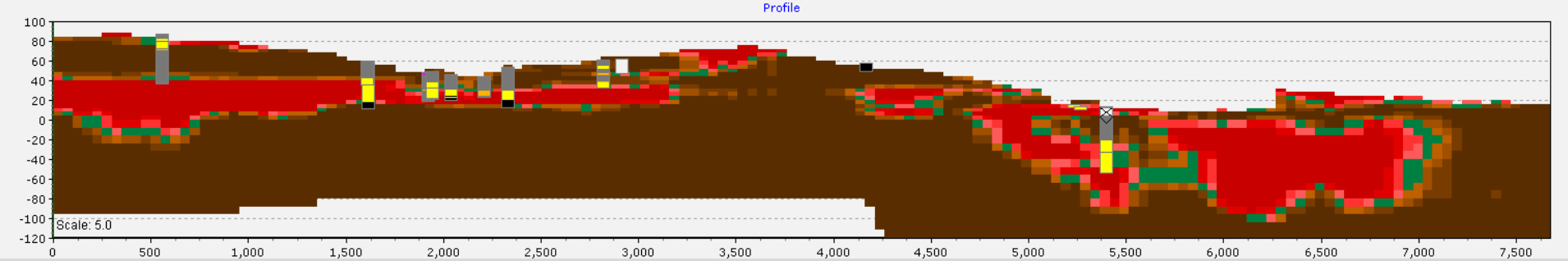


Sections

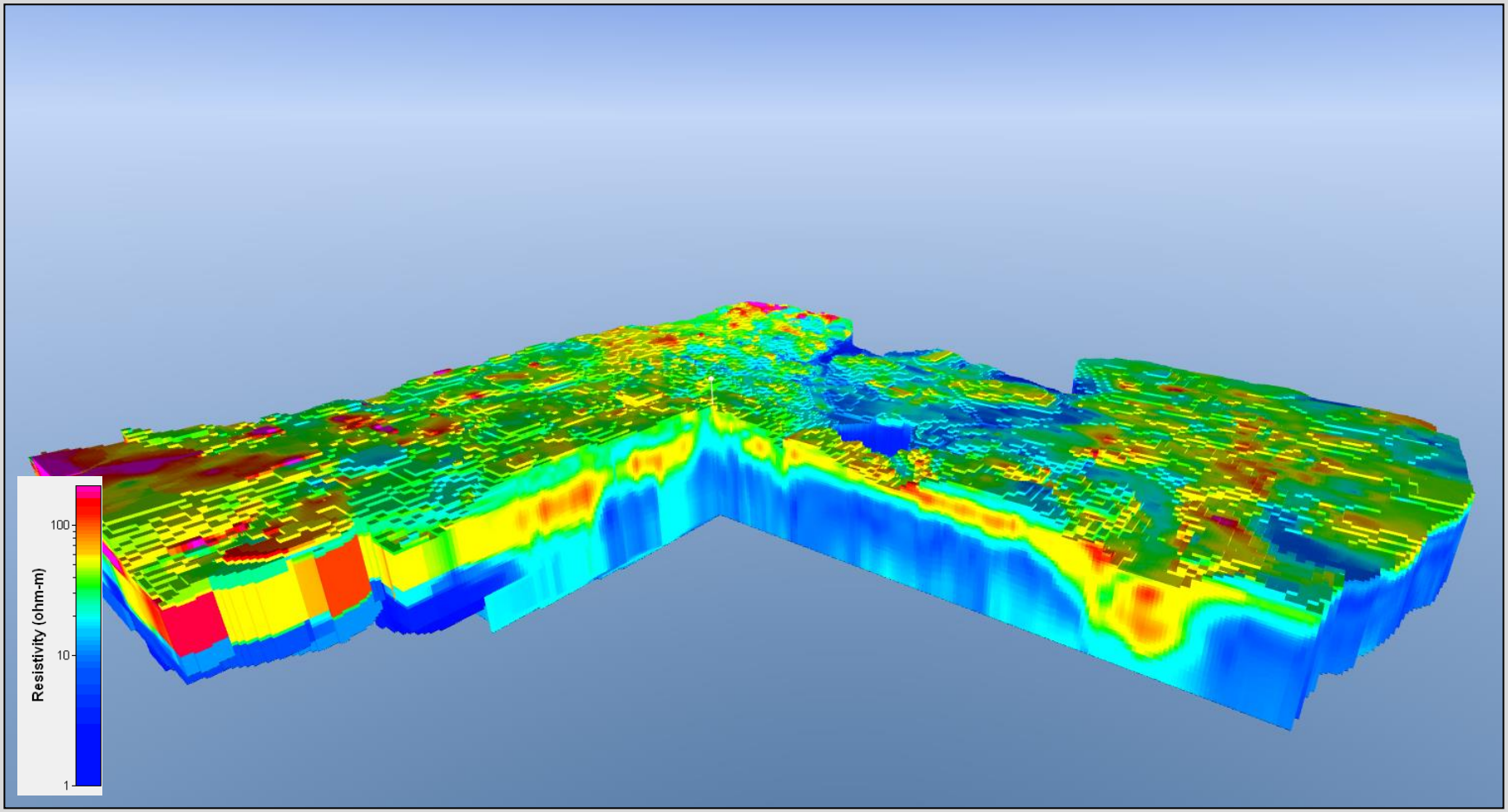

Ajstrup Strand
Norsminde
Kysing Næs
Kysing
ODDER
Saksild Bugt


Profile
Scale: 5.0

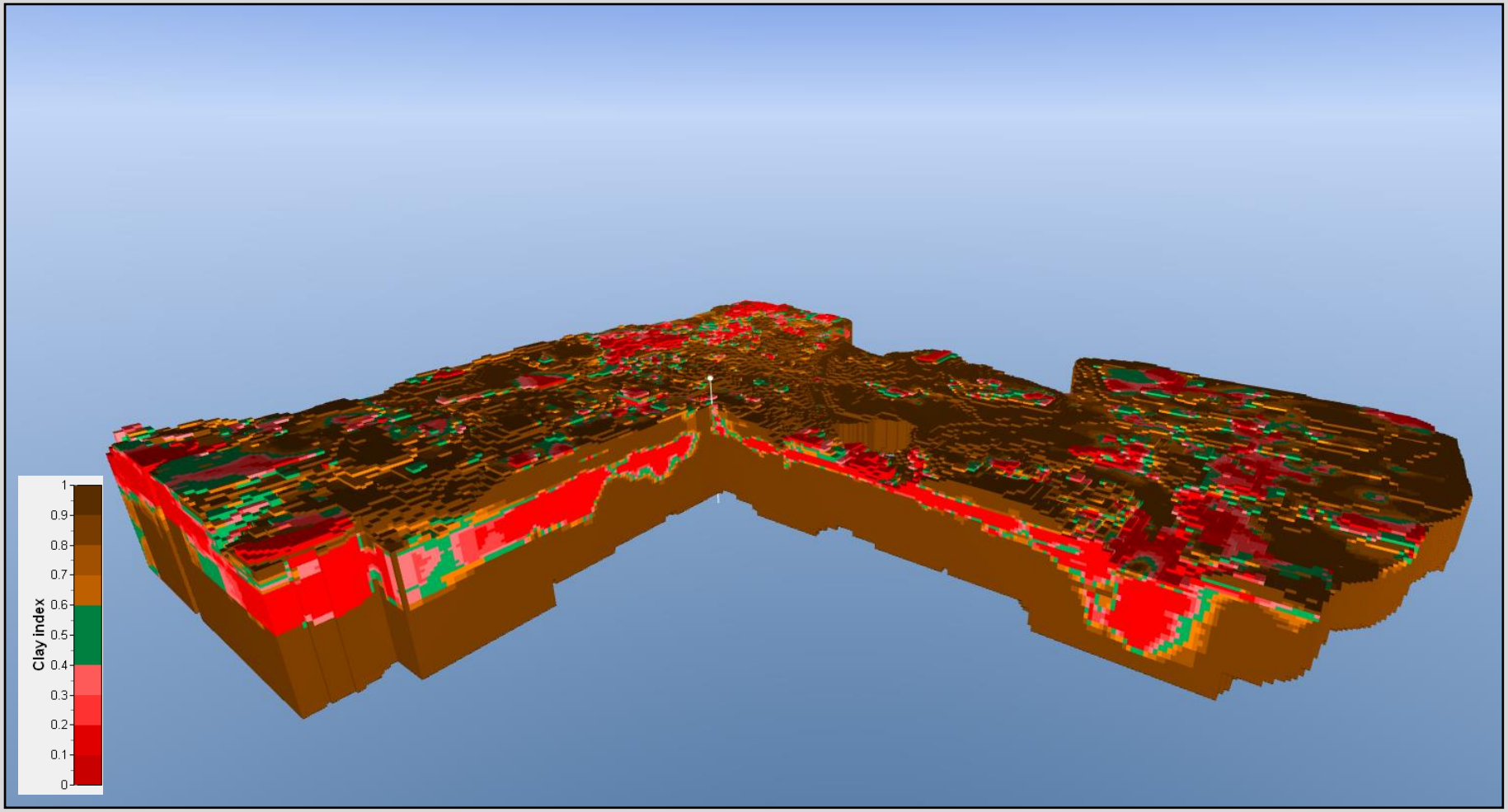

Profile
Scale: 5.0


Profile
Scale: 5.0

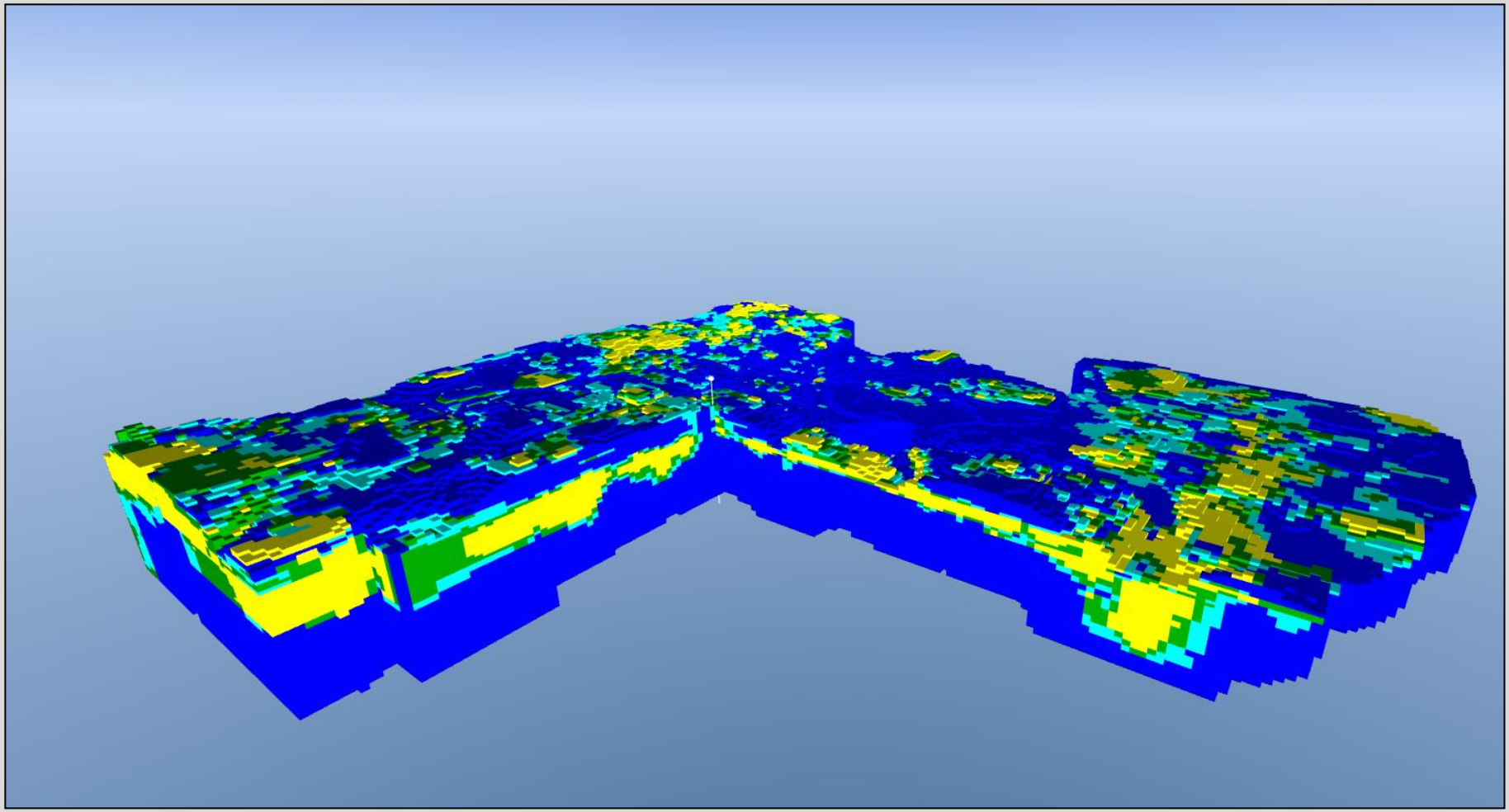
3D – Resistivity



3D – Clay fraction

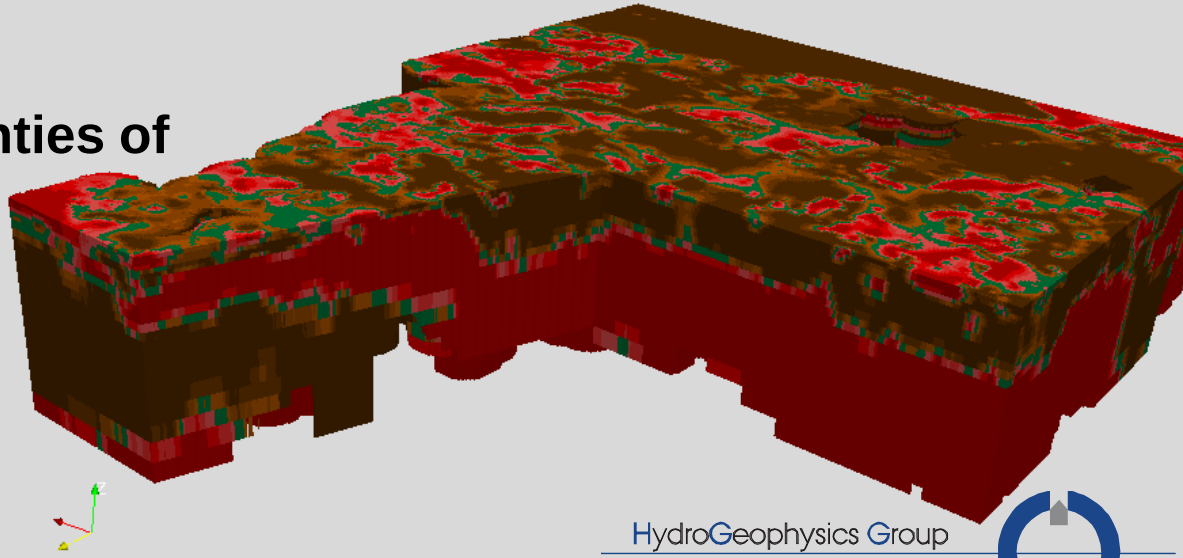


3D – classification



Summary / Discussion

- **We obtain the best resistivity-to-clay translation integrating borehole information**
- **We obtain a simple geological sand/clay model**
  - Starting point for more advanced geological models
  - Input to groundwater models through classification (or direct?)
- **Objective approach**
  - Reproducible
  - Well-documented
- **Incorporates uncertainties of**
  - geological information
  - geophysical information
  - spatial interpolation



Large-scale automatic generation of hydrological input from resistivities and boreholes

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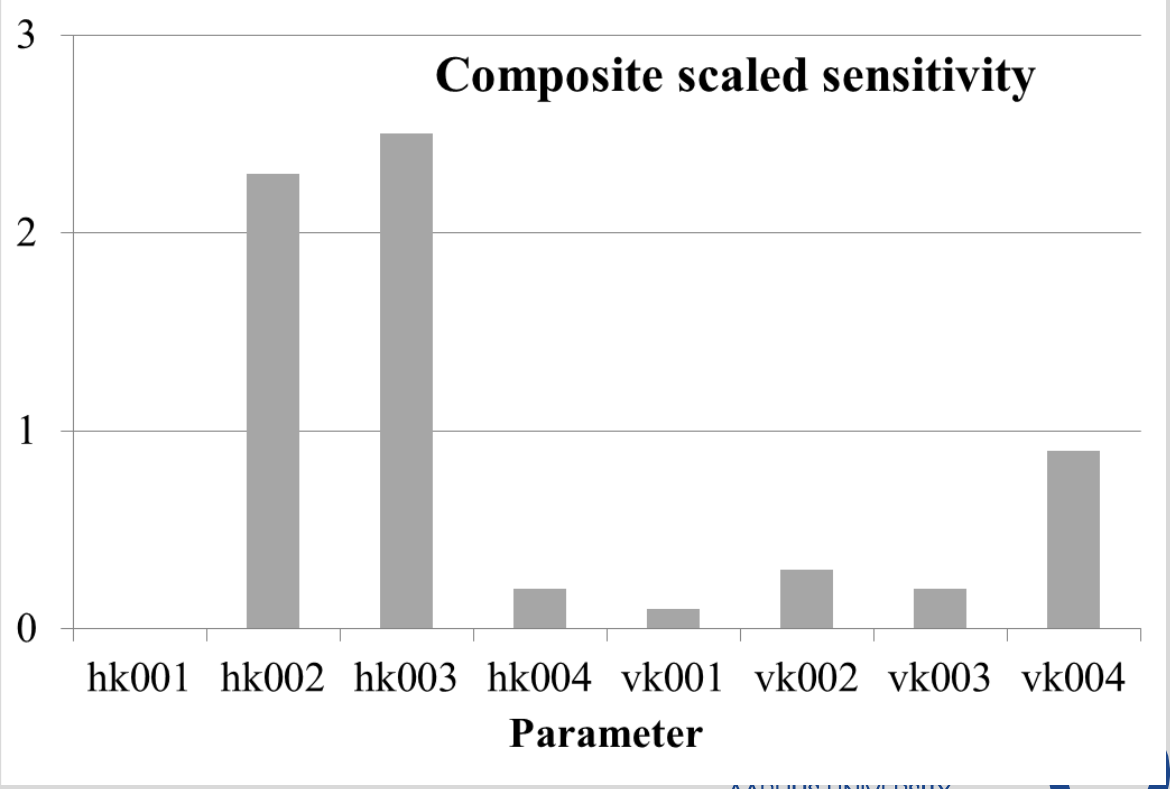
HydroGeophysics Group
AARHUS UNIVERSITY

Local sensitivity of classes

$$ss_{ij} = \left(\frac{\Delta obs_i}{\Delta par_j / par_j}\right)\frac{1}{\sigma_{ii}}$$

$$css_j = \left(\sum_{i=1}^{N} {ss_{ij}}^2 / N\right)^{1/2}$$



Hydraulic conductivity fields

Group	Geo unit	HK [m/s]	VK [m/s]
1	glacial sand	3.31E-05	3.31E-06
4	glacial clay	1.14E-08	1.14E-09
1	tectonic sand	2.00E-05	2.00E-06
2	tectonic clay	6.21E-08	6.21E-09
1	tunnel valley sand	2.00E-05	2.00E-06
2	tunnel valley clay	6.21E-08	6.21E-09
3	miocene sand	3.31E-05	3.31E-06
2	miocene clay	3.31E-08	3.31E-09
4	paleogene clay	1.10E-10	1.10E-10

Parameter	HK [m/s]	VK [m/s]
hk001/vk001	7.44E-07	7.44E-07
hk002/vk002	6.32E-06	6.32E-07
hk003/vk003	1.86E-03	1.86E-04
hk004/vk004	1.00E-09	1.00E-10